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AIRPORT CAPACITY INVESTMENT HANDBOOK

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Transportation Systems Center
Cambridge MA 02142

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16. Abstract

This handbook provides a methodology for estimating the benefits and costs of capacity-related investments in airports in the United States. The procedures are laid out in a series of worksheets. The user provides certain basic information such as expected traffic levels, aircraft type mix, operations rates before and after the investment, and construction costs. Following the procedures laid out in the worksheets, he then estimates airport delay reduction benefits, system-wide delay reduction benefits, and the benefits of reduced diversions due to new runway construction. These benefits are converted to dollars, discounted over a twenty year period, and compared to costs similarly discounted, to arrive at an approximate benefit/cost ratio.

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PREFACE

This AIRPORT CAPACITY INVESTMENT HANDBOOK provides a standard methodology for estimating the benefits and costs of investments made under the Federal Airport Development Aid Program that are intended primarily to improve airport capacity. The user of this Handbook supplies basic information such as the IFR and VFR capacity of the airport before and after the investment, the projected traffic level and aircraft mix at the airport, and the cost of the investment. Following the procedures laid out in a series of Worksheets, he then obtains estimates of the economic benefits expected to accrue due to reductions in delays and diversions brought about by the capacity increase. These benefits, and the associated costs, are discounted and summed over a twenty year period to obtain a net benefit/cost estimate for the investment.

The tables and charts in this Handbook were generated by two computer models, the Airport Performance Model (APM) and the Airport Network Flow Simulator (ANFS), References (1) and (2). The models were developed at the U.S. Department of Transportation, Transportation Systems Center, for the Federal Aviation Administration, Office of Aviation System Plans. It is recommended that users of this Handbook review the underlying computer models referred to in order to obtain an understanding of the methodology before using the Handbook.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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1. INTRODUCTION

This handbook has been developed for use by airport planners and transportation analysts. Its purpose is to provide a standard methodology for estimating the magnitude of certain types of benefits arising from investments in airside capacity. The methodology has been reduced to simple calculations carried out on prepared Worksheets, provided in the Appendix and illustrated in the text. Together with a guide to airport capacity, such as "Airport Capacity Criteria Used in Long Range Planning," Reference (3), it forms a self-contained tool for benefit/cost analysis of investments in airport capacity.

1.1 TYPES OF INVESTMENT BENEFITS TREATED

This handbook treats three different types of airport capacity benefits. First, the handbook presents a technique for estimating the benefits of runway delay reductions on arrival and departure brought about by the capacity increase. Second, a method is presented for quantifying the specific benefits of cross wind runways in reducing airport diversions due to high winds. Finally, long delays in scheduled operations at one airport can lead to further departure flight delays at airports served by continuing flights. This handbook provides a technique for estimating the benefits of reducing these "cascading" or airport system wide delays. The end product of these procedures is an estimate of the total capacity-related benefits over a 20-year economic lifetime of the investment, and the determination of the ratio of project benefits to project costs.

1.2 LIMITATIONS OF THIS HANDBOOK

The charts and tables of this handbook are based on the assumptions of the underlying computer models and on the necessarily limited data available. Hence the results must be considered only an approximation of the true benefits to be derived from any

given investment. In particular the procedure is confined to the three types of benefits described above, and does not include the effects of noise on the surrounding community, or of changes in the level of air and water pollution. In most cases more accurate estimates of benefits can be derived by examining detailed airport-specific factors in a framework developed for a particular airport. Such analyses are necessarily expensive and time consuming. For many investments, the procedures presented in this handbook can be used to develop approximate airport investment benefits quickly and at little expense. For certain investments, the airport planner may choose to make use of the computer programs (documented in References 1 and 2) that underlie the tables and graphs of this handbook, and which can be used to develop more accurate estimates of capacity improvement benefits. These computer programs are presently in operation at the Federal Aviation Administration, Office of Aviation System Plans.

The computer program used to develop the airport delay charts (Reference 1) is a deterministic digital simulation of arrival and departure queues at 31 selected U.S. airports. The results of many runs were grouped by airport type to produce the delay charts of Section 3. The computer program used to develop the system-wide delays and benefits of Section 5 is a simulation of delay propagation throughout a network of 665 U.S. commercial airports. Again the chart in Section 5 is the result of several runs of the sumulator.

1.3 PROCEDURE

The user of this handbook must gather data describing the operating environment at the airport being analyzed. This information deals with current and projected runway processing rates with and without the investment under consideration, the mix of private and commercial aircraft using the airport, and other items that are specified in the following Table 1:

TABLE 1. REQUIRED AIRPORT OPERATING DATA

Data Required	Worksheet/Page
Total Airport Operations, 1st and 10th Year of Invesmtnent	1/1
Scheduled Aircraft Operations, 1st and 10th Year	1/1
Mix of Scheduled Aircraft Types	1/1
Mix of Nonscheduled Aircraft Types	1/1
Fraction of IFR Weather Days	1/1
Fraction of VFR Weather Days	1/1
Processing Rates Without Investment	2/1
Processing Rates With Investment	2/2
Airport Wind Rose (Figure 26)	8/1
Capital Investment, By Year	11/1
Operating Expense, By Year	11/1
Operating Receipts, By Year	11/1

In most cases this information has been tabulated previously for a number of airports. In other cases, circulars and guides for airport planning can be used to develop the necessary information. The user's professional judgment is required in some cases to forecast certain aspects of the airport operating environment in future years.

It should be noted also that some calculations, such as those involving aircraft operating costs, employ dollar values that were current at the time of Handbook preparation. It may be necessary to adjust some of the constants employed in the Worksheets used in the calculations. The constants that may need adjustment are given in the following Table 2:

TABLE 2. ADJUSTABLE COSTS

Constants	Worksheet/Page
Hourly Operating Cost on Landing, By Aircraft Type	5/1
Hourly Operating Cost on Takeoff, By Aircraft Type	5/1
Value of Passenger Time	6/1
Value of Passenger Time	7/3
Cost per Diversion, Air Carrier	9/1
Cost per Diversion, Air Taxi	9/1
Cost per Diversion, General Aviation and Military	9/1

The computation required to use this handbook can be performed easily without the use of a computer --the user is simply required to gather the specified data and read delay and diversion reduction impacts from figures and tables. The economic benefits of airport capacity projects are calculated directly using the worksheets provided in Appendix A. Sample calculations are carried out throughout the text for a hypothetical investment at YNG, Youngstown Ohio Municipal Airport.

1.4 HANDBOOK ORGANIZATION

The flow chart shown in Figure 1 shows the steps required in evaluating an airport capacity investment. Each box in the Figure corresponds to a Section of the handbook and to one or more Worksheets. Seperate Sections are devoted to the development of benefits from the reduction of: (1) airport runway delays, (2) aircraft diversions, and (3) system wide or "cascading" airport delays due to capacity improvements. Note that benefits from reduced aircraft diversions will be generated primarily from investments that improve airport capacity during conditions of

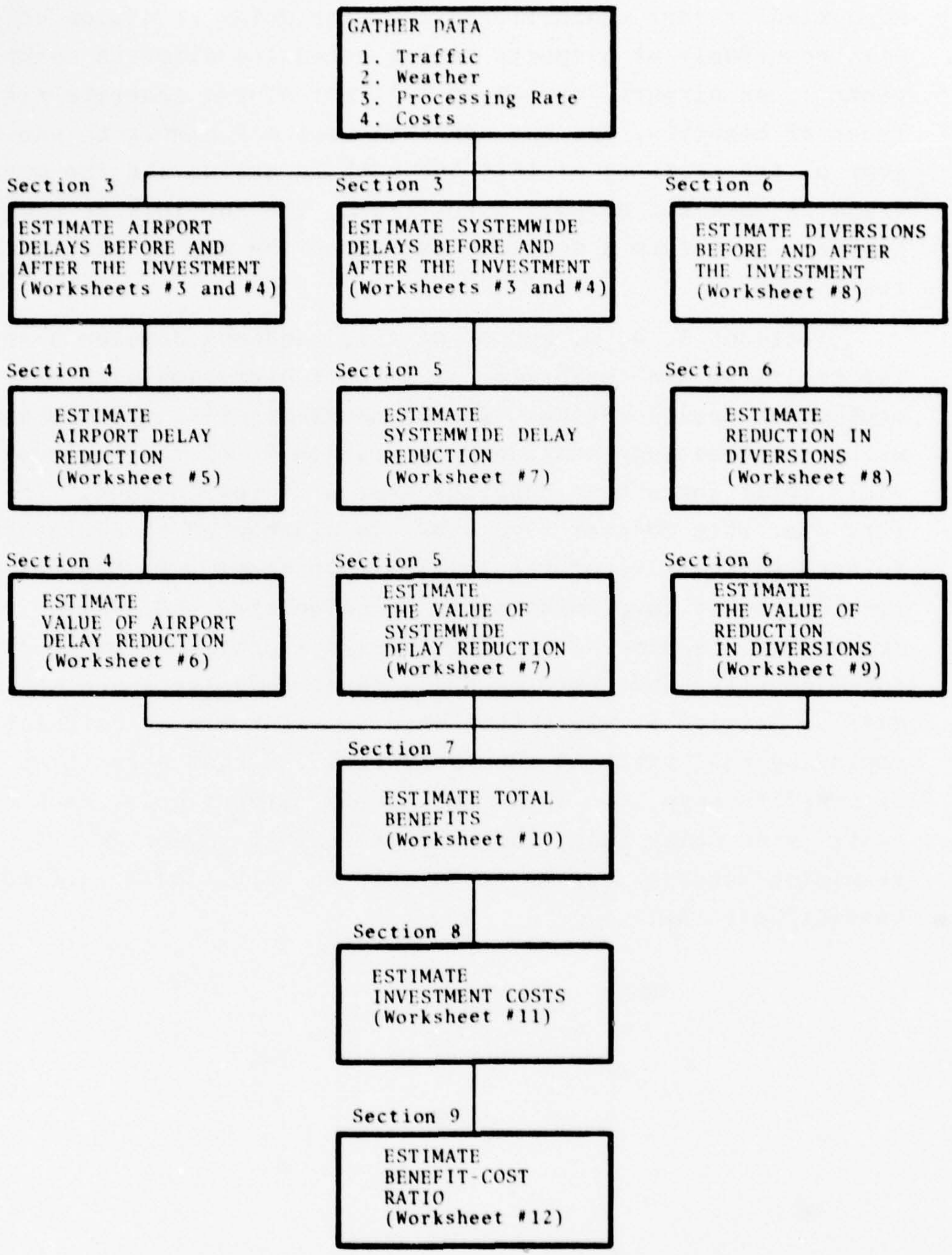

FIGURE 1. ORGANIZATION OF HANDBOOK

high wind or poor weather. System wide delay reduction benefits will occur only at airports having scheduled aircraft service. In general, an airport investment will not always generate all three types of benefits, and the handbook user may choose to use only some of the sections of this handbook in evaluating the desirability of a specific airport investment. The sections he chooses, however, must form a complete path from the top of the chart to the bottom.

Sections 3, 4, 5, and 6 of this handbook develop benefits for the first and tenth year of airport operation with the investment under consideration. These annual benefits are combined using a methodology contained in Section 7. of the handbook to yield total investment benefits over a 20-year period. The benefits over this 20-year time span are discounted to equivalent dollars at the time of the initial investment. In Section 8 the time stream of investment costs is calculated and similarly discounted to the time of the initial investment. A comparison of total benefits and costs of the airport capacity investment is made in Section 8, where the Benefit/Cost ratio is calculated. In employing this ratio it should be realized that only three types of benefits have been included, namely airport delay reduction, system-wide delay reduction, and diversions reduction. The resulting Benefit/Cost ratio is only an approximation of the Benefit/Cost ratio.

2. GATHER DATA

The user of this handbook must provide certain information about the airside operating characteristics of the airport. The major items to be provided deal with runway processing rates, weather, number of operations, mix of aircraft, and number of passengers, as listed in the preceding Section.

The impact of an investment on an airport's performance will be examined for the first and tenth year of use for the proposed investment, so airport demand and capacity information must be forecast for both these years. Throughout the handbook these years will be referred to as YEAR 1 and YEAR 10. The user should be aware that YEAR 1 is the first full* year in which benefits can accrue to the investment and may be several years after the first year in which costs are incurred. The difference between first year of costs and first year of benefits will be accounted for in Sections 8 and 9.

The data gathered in this Section will be entered on Worksheets #1 and #2, provided at the end of the handbook. The information required for these Worksheets will now be described.

2.1 ANNUAL AIRCRAFT OPERATIONS

The number of annual aircraft operations to be served at the airport must be provided in analyzing the airport investment benefits. Projections of airport operations should be provided for scheduled operations (by air carriers and air taxi), and non-scheduled operations (made by general aviation and military aircraft). Projections of activity for many airports are provided directly by the Terminal Area Forecast (Reference 4). Traffic

*If the improvement reaches operational status in the first six months of the year, it should be assumed to have been operating from the beginning of the year. If it begins operation in the second six months of the year, it should be assumed that operation does not begin until the start of the next year. Either fiscal or calendar years may be employed in using this Handbook, but not both.

forecasts in this reference are in the proper format for developing the information needed by this handbook. Airport traffic projections must be provided for the first and tenth year of airport operation with the investment in place and operational.*

2.2 AIRPORT FLEET MIX

The mix aircraft types operating at an airport is defined in this handbook to mean the fraction of total annual airport operations made by each of a series of seven aircraft categories. The airport fleet mix projections are to be made separately for scheduled and nonscheduled aircraft, and then combined using the operations data previously developed. Airport fleet mix must be projected for the first and tenth year of airport operations after the investment under consideration is in place and operational. Airport fleet mix has been projected to the year 2000 for over 100 U.S. airports in Reference 5 . If previous projections of airport fleet mix have not been made, the analyst must use professional judgement and knowledge in developing fleet mix projections for the airport of interest. Historical data on scheduled fleet mix is documented periodically in Airport Activity Statistics (Reference 6); and these past reports may be used as a guide to fleet mix projections for scheduled operations. Projections of aircraft fleet mix for non-scheduled operations can be derived similarly using historical records of airport operations by general aviation or military aircraft. The aircraft categories used by this handbook are defined in Table 3.

2.3 AIRPORT IFR/VFR WEATHER FREQUENCY

Weather plays a significant role in influencing airport delays. Conditions of low ceiling and visibility causing Instrument Flight Rules (IFR) operating procedures can increase the time required between aircraft operations and thereby increase delays. Airports experiencing IFR weather a high percentage of the time should be

*The same traffic is to be assumed to occur without the investment as with it so that a valid comparison of delay reduction may be obtained.

TABLE 3. DEFINITIONS OF AIRCRAFT CATEGORIES

Aircraft Category	Typical Aircraft Included
1. 4 Engine, Wide Body JET	B-747, B-747F
2. 2, 3 Engine, Wide Body JET	L-1011, DC-10, A300B
3. 4 Engine, Standard Body JET	B-707, DC-8
4. 3 Engine, Standard Body JET	B-727
5. 2 Engine, Standard Body JET	B-737, DC-9, BAC-111
6. Large Turboprop, Piston	L-188, CV-580, M-404, etc.
7. Small (<12,500 lb)	Beech 99, DHC Twin Otter, Piper Aztec, etc.

expected to have different airport delay characteristics than airports rarely experiencing IFR weather. Historical airport weather characteristics have been tabulated for 271 U.S. airports in Reference 7, and airport planners can make use of this source in estimating future weather characteristics for an airport.

For this handbook, the relevant measure of airport weather is the fraction, f_I, of the time IFR weather is in effect over an "average" year. IFR weather is defined as ceilings below 1500 feet or visibility less than 3 miles. One minus the fraction, f_V, of VFR weather. Planners without access to Reference 7 may be able to approximate these fractions by examining the data presented in Table 4 for a range of U.S. locations. Care must be exercised in employing Table 4 because local conditions, such as bodies of water, nearby mountains and airport altitude can cause the ceiling and visibility conditions at the airport to differ markedly from those in the surrounding region. The local Federal Weather Service station may provide assistance for obtaining accurate data.

2.4 RUNWAY PROCESSING RATES

Airport runway processing rates are defined here to mean the maximum number of aircraft arrivals and departures that can be served in an hour by an airport's runway system. To evaluate the benefits of an airport investment, the user of this handbook must provide the runway processing rates for IFR and VFR weather for the airport runway system with the addition of the investment under consideration, and for comparison, without the investment. These processing rate estimates must be provided for the first and tenth year that the investment is scheduled to be operational, as shown on Worksheet #2.

The procedure of Worksheet #2 is only one of several possible procedures for estimating IFR and VFR processing rates. If a more accurate or more convenient procedure is available to the user, he may employ it, provided it gives average IFR and VFR processing rates for Year 1 and Year 10.

TABLE 4. REPRESENTATIVE VALUES FOR FREQUENCY OF IFR CONDITIONS

East		**South**	
Bangor	19.7	Montgomery	10.0
Burlington	8.4	Shreveport	11.4
New York	16.5	Little Rock	9.6
Rochester	11.3		
Washington DC	11.5	**Southwest**	
Pittsburgh	17.1	Tulsa	9.0
		Dallas	8.7
Mid-West		Corpus Christi	12.7
Detroit	14.1	Lubbock	8.0
Cincinnati	14.5	Albuquerque	1.1
Chicago	16.3	Phoenix	0.4
Minneapolis	11.5		
Des Moines	12.2	**Great Plains**	
St. Louis	11.1	Kansas City	10.0
		Wichita	10.5
South		Fargo	12.0
Tampa	6.7	Bismark	10.5
Atlanta	14.5	Rapid City	8.1
Winston-Salem	13.7	Sioux Falls	12.5
Nashville	10.1		
Rocky Mountains		**Pacific**	
Pueblo	5.3	San Diego	19.3
Cheyenne	9.2	Los Angeles	25.7
Billings	5.7	Fresno	9.2
Helena	2.4	San Francisco	15.5
Boise	4.7	Portland	11.0
Salt Lake City	5.5	Seattle	16.3
Las Vegas	0.3	Spokane	14.3
Reno	1.6	Juneau	7.4
		Anchorage	8.8
		Fairbanks	7.9
		Honolulu	0.5

Source: Reference 4 .

Many airports have several different operating configurations that are used under different wind conditions. When an airport has several different processing capacities because of alternative runway use patterns, the user should estimate the percentage of time each configuration is used, and use these fractions to develop annual average processing rates for IFR and VFR conditions.

Previous airport capacity studies (such as Reference 3 and 8) can be useful in estimating the aircraft processing rate for different runway configurations. These studies also indicate how airport fleet mix changes affect processing rate. If an airport planner anticipates a significant change in airport fleet mix between the first and tenth years of airport operation with the new investment, this fleet mix change may result in processing rate changes between the two time periods for the same runway configurations.

The procedure for gathering the data and filling in Worksheets #1 and #2 is illustrated by the following hypothetical investment at YNG.

2.5 SAMPLE CALCULATION: ANNUAL AIRCRAFT OPERATIONS

Consider a hypothetical airport runway investment in 1977 at Youngstown Ohio Municipal (YNG). Although the first expenses are incurred in 1977, the analyst assumes that 1979 would be the first year of airport operation with the new runway in place if the investment is made. Therefore 1988 would be the tenth year of aircraft operation with the investment. The analyst determines the volume of aircraft operations to be accommodated by using the Terminal Area Forecast (Reference 4). Activity projections for YNG from that Reference are reproduced on the following page.

TERMINAL AREA FORECAST FOR YNG (Reference 4)

COMMUNITY: YOUNGSTOWN   AIRPORT NAME: YOUNGSTOWN MUNI   LOC ID: YNG
BASED AIRCRAFT: 57   ITIN. OCCUPANTS-1974 (000): 476   TOWERED

	ACTUAL			FORECAST		
	FY 1975	FY 1977	FY 1978	FY 1979	FY 1982	FY 1987
ENPLANED PASSENGERS (000)						
AIR CARRIER	136*	155	165	173	204	277
AIR TAXI	0*	1	2	2	3	4
OPERATIONS (000)						
AIR CARRIER	8	8	9	9	10	12
AIR TAXI	1	1	1	1	1	1
ITINERANT	53	59	64	69	83	107
TOTAL	89	99	109	118	147	196
INSTRUMENT	42	46	50	54	65	84
INSTRUMENT APPROACHES	3889	4380	4712	5030	5876	7384

From this information the analyst learns that YNG is projected to have 9,000 + 1,000 = 10,000 operations by air carrier and air taxi in 1979. These are taken to be the entirety of scheduled operations in 1979. The remainder of total operations in 1979, or 118,000-10,000 = 108,000 operations are made by general aviation and military aircraft, and are referred to as nonscheduled operations. The analyst develops the following airport operations projections from the Terminal Area Forecast information from YNG:

Operations	1979	1988
Scheduled	10,000	13,400
Nonscheduled	108,000	192,400
Total	118,000	205,800

In order to obtain the projections for 1988, which are not given in the forecast, it was assumed that traffic continues to grow beyond 1987 at the same rate it is projected to increase from 1982 to 1987. This rate is approximately (12,000-10,000)/5=400 operations per year for air carrier, 0 for air taxi, and approximately (196,000-147,000)/5=9,800 operations per year total. Thus the scheduled traffic projection for 1988 is 13,400 operations and the total traffic projection is 205,800 operations.

The above projections are entered onto Worksheet #1 on lines 1. and 2. Nonscheduled operations, line 3., are obtained by subtraction. Lines 4. and 5., the fraction of scheduled and nonscheduled operations, are obtained by dividing lines 2. and 3. by line 1., and will be used later.

WORKSHEET #1: OPERATIONS & WEATHER DATA

		YEAR 1 (1979)	YEAR 10 (1988)
OPERATIONS			
[1] =Total Operations	=	118,000	205,800
[2] =Scheduled Operations	=	10,000	13,400
[3] =Non-Scheduled Operations =[1]-[2]	=	108,000	192,400
[4] =Fraction Scheduled [2]/[1]	=	.085	.065
[5] =Fraction Non-Scheduled [3]/[1]	=	.915	.935
AIRCRAFT MIX, SCHEDULED			
[6] =4 engine Wide Body Jet	=	.00	.00
[7] =2, 3 engine Wide Body Jet	=	.00	.00
[8] =4 engine Standard Body Jet	=	.00	.00
[9] =3 engine Standard Body Jet	=	.25	.30
[10] =2 engine Standard Body Jet	=	.45	.50
[11] =Large Turboprop, Piston	=	.30	.20
[12] =Small (<12,500 lb)	=	.00	.00
		1.00	1.00
AIRCRAFT MIX, NON-SCHEDULED			
[13] =4 engine Wide Body Jet	=	.00	.00
[14] =2, 3 engine Wide Body Jet	=	.00	.00
[15] =4 engine Standard Body Jet	=	.00	.00
[16] =3 engine Standard Body Jet	=	.00	.00
[17] =2 engine Standard Body Jet	=	.00	.00
[18] =Large Turboprop, Piston	=	.10	.10
[19] =Small (<12,500 lb)	=	.90	.90
		1.00	1.00
AIRCRAFT MIX, TOTAL			
[20] = [4] x [6] + [5] x [13]	=	.00	.00
[21] = [4] x [7] + [5] x [14]	=	.00	.00
[22] = [4] x [8] + [5] x [15]	=	.00	.00
[23] = [4] x [9] + [5] x [16]	=	.02	.02
[24] = [4] x [10] + [5] x [17]	=	.04	.03
[25] = [4] x [11] + [5] x [18]	=	.12	.11
[26] = [4] x [12] + [5] x [19]	=	.82	.84
		1.00	1.00
WEATHER FRACTIONS			
[27] =Fraction f_I of IFR weather	=	.21	.21
[28] =Fraction f_V of VFR weather (1.0-[27])	=	.79	.79

2.6 SAMPLE CALCULATION: AIRPORT FLEET MIX

Continuing our hypothetical example using YNG, the analyst would first consider the rescheduled fleet mix. Data found in Reference 6 indicate the trends in scheduled aircraft operations at YNG as shown in Table 5:

TABLE 5. TREND IN SCHEDULED AIRCRAFT MIX AT YNG

Aircraft Type	Percent of Annual Operations 1971	1974
1. 4 Engine Wide Body JET	0.0	0.0
2. 2, 3, Engine Wide Body JET	0.0	0.0
3. 4 Engine Standard Body JET	0.0	0.0
4. 3 Engine Standard Body JET	12.7	24.0
5. 2 Engine Standard Body JET	59.8	44.1
6. Large Turboprop, Piston	27.5	31.7
7. Small (<12.500 lb)	0.0	0.0
	100.0	100.0

Based on this information (and no judgment as to the probable equipment replacement actions to be made over the next 10 years), the analyst can develop a projection of scehduled aircraft fleet mix over the next 10 years. One plausible scheduled aircraft fleet mix for 1979 and 1988 might be as follows (Table 6):

TABLE 6. PROJECTED SCHEDULED AIRCRAFT MIX FOR YNG (PERCENT)

	1979	1988
3 Engine, Standard Body JET	25	30
2 Engine, Standard Body JET	45	50
Large Turboprop, Piston	30	20
	100	100

Consider next the nonscheduled aircraft mix. For airport planners in certain states or regions, the mix of nonscheduled aircraft can be projected by reviewing the fleet mix trends revealed by surveys of general aviation/military fleet mix characteristics at the airport being considered. However, not all states have carried on such surveys in the past, and airport planners in those areas must use more approximate methods for forecasting an airport's future nonscheduled aircraft fleet mix. A brief review of the aircraft based at an airport will in most cases help an analyst get a clear idea of the range and relative group size of the types of aircraft that perform most of an airport's nonscheduled operations. For the sample calculation, as seen in lines 13. through 19. of Worksheet #1, the analyst has used averages of 10 percent large turboprop or piston, and 90 percent small aircraft types (less than 12,500 pounds gross take off weight) in both 1979 and 1988.

The scheduled and nonscheduled aircraft fleet mix projections for 1979 and 1988 must now be combined to form the total airport fleet mix using the fractions of total annual operations made by scheduled and nonscheduled aircraft as weighting factors, as shown in the calculations detailed on lines 20. through 26. of Worksheet #1. The result of this weighted average for the sample investment problem for YNG is shown in Table 7 below and on the sample Worksheet #1.

TABLE 7. TOTAL AIRPORT FLEET MIX PROJECTIONS (PERCENT)

		1979	1988
(23.)	3 Engine, Standard Body JET	2	2
(24.)	2 Engine, Standard Body JET	4	3
(25.)	Large Turboprop Piston	12	11
(26.)	Small (<12,500 lb)	82	84
		100	100

2.7 SAMPLE CALCULATION: AIRPORT IFR/VFR WEATHER FREQUENCY

The data shown below for Youngstown Municipal Airport have been reproduced in Table 8 from Reference 7. They indicate that IFR conditions have been observed 20.8% of the time historically from 1948 through 1964 at YNG. VFR conditions have been observed 100%-20.8% = 79.2 percent of the time. These two percentages are seen at the bottom of columns (1) and (2). The frequency of occurrence of IFR and VFR weather conditions are referred to as f_I and f_V respectively in later portions of this handbook. Their values for YNG have been entered in lines (27.) and (28.) of Worksheet #1.

2.8 SAMPLE CALCULATION: RUNWAY PROCESSING RATE

For this sample calculation, assume that YNG has a single runway with the addition of a second crossing runway under consideration. For the sake of discussion, assume the original runway will be designated runway 7/25, and the proposed crossing runway will be designated 12/30. The analyst studies airport wind rose data and estimates that 65 percent of the time, the new runway configuration will be used with the intersection of the runways occurring at the near threshold. The remaining 35 percent of the time the runway intersection will occur near the far threshold with a resulting decrease in operating capacity. Without the investment, the airport runway capacity is that of a single runway facility, and the capacity in either direction of operation is the same.

The airport planner has decided to employ the procedure outlined on Worksheet #2 rather than develop independent estimates of net processing rates with and without the investment he has already estimated the mix of aircraft to be served at the airport in YEAR 1 and YEAR 10, as he entered on Worksheet #1, lines 20. through 26. The estimates as to airport fleet mix and direction of aircraft operations are laid out with runway configuration diagrams in Figure 2. as an aid to visualization. The airport planner uses these assumptions in conjunction with airport capacity planning manuals (such as References 3 and 8) to determine hourly IFR and VFR runway processing rates for the airport in 1979 and 1988,

TABLE 8. CEILING AND VISIBILITY DATA FOR YNG (REFERENCE 7)

CEILING VS. VISIBILITY CLIMATOLOGICAL STUDY (HOURLY OBSERVATIONS)

STATION#14852 YOUNGSTOWN, OHIO

PERIOD OF RECORD 1/48-12/64

HOUR GROUP		NO.OF OBS	CEILING-VISIBILITY CATEGORIES (%) (1)	(2)	(3)	(4)	(5)	(6)	SYSTEM ENHANCEMENT FACTORS (%) VOR	CAT1	CAT2	MIN*
JAN	ALL	12642	64.7	35.3	28.2	5.2	0.9	1.0	79.9	14.7	2.7	2.8
FEB	"	11535	67.7	32.3	25.2	4.9	1.1	1.1	78.0	15.1	3.4	3.5
MAR	"	12642	72.6	27.4	22.2	3.9	0.7	0.5	81.2	14.2	2.6	2.0
APR	"	12233	80.9	19.1	16.0	2.0	0.5	0.6	83.7	10.6	2.7	3.0
MAY	"	12640	86.7	13.3	11.1	1.8	0.2	0.2	83.6	13.5	1.5	1.4
JUN	"	12238	87.6	12.4	10.2	1.5	0.4	0.3	82.6	11.8	2.8	2.8
JUL	"	12648	88.4	11.6	9.4	1.2	0.3	0.6	81.2	10.8	2.6	5.5
AUG	"	12639	86.4	13.6	11.0	1.5	0.4	0.8	80.5	11.1	2.6	5.7
SEP	"	12237	87.6	12.4	10.1	1.3	0.3	0.6	81.7	10.8	2.5	5.0
OCT	"	12643	83.8	16.2	13.5	1.7	0.3	0.7	83.6	10.4	1.9	4.1
NOV	"	12235	76.9	23.1	19.2	2.8	0.5	0.6	83.0	12.0	2.4	2.6
DEC	"	12645	66.6	33.4	26.9	4.2	1.1	1.2	80.4	12.6	3.3	3.7
ANN	07-13	43460	73.1	26.9	22.5	3.3	0.6	0.5	83.7	12.1	2.1	2.0
	14-21	49654	85.3	14.7	12.3	1.9	0.3	0.2	83.7	12.7	2.0	1.7
	22-06	55863	78.5	21.5	16.6	2.9	0.8	1.2	77.2	13.5	3.7	5.6
	ALL	148977	79.2	20.8	16.9	2.7	0.6	0.7	81.2	12.8	2.7	3.3

CEILING VISIBILITY CONDITIONS (% OF TOTAL OBSERVATIONS)

(1) ≥ 1500 FEET AND 3 MILES

(2) < 1500 FEET AND/OR 3 MILES

(3) < 1500 FEET AND/OR 3 MILES, BUT ≥ 400 FEET AND 1 MILE

(4) < 400 FEET AND/OR 1 MILE, BUT ≥ 200 FEET AND 1/2 MILE

(5) < 200 FEET AND/OR 1/2 MILE, BUT ≥100 FEET AND 1/4 MILE

(6) < 100 FEET AND/OR 1/4 MILE

SYSTEMS ENHANCEMENT FACTORS
(CEILING VISIBILITY CONDITIONS)

VOR=FREQ (3)/FREQ(2)

CAT1 ILS=FREQ(4)/FREQ(2)

CAT2 ILS=FREQ(5)/FREQ(2)

*BELOW MINIMUMS=FREQ(6)/FREQ(2)

WORKSHEET #2: PROCESSING RATES

PROCESSING RATES WITHOUT INVESTMENT

RWY CONF.	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR	x (% USE / 100) =	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR
A: 7 D: 7	99	53	99	53	x(.65) =	64.	34.	64	34
A: 25 D: 25	99	53	99	53	x(.35) =	35.	19.	35	19
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
NET PROCESSING RATES WITHOUT INVESTMENT =						99 [29]	53 [30]	99 [31]	53 [32]

WORKSHEET #2
2/2

PROCESSING RATES WITH INVESTMENT

RWY	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR	x $\left(\frac{\%\ USE}{100}\right)$		YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR
A:7 D:12	175	71	175	71	x( )	=	114	46	114	46
A:25 D:30	99	55	99	55	x( )	=	34	19	34	19
					x( )	=				
					x( )	=				
					x( )	=				
					x( )	=				
					x( )	=				
					x( )	=				
					x( )	=				
NET PROCESSING RATES WITH INVESTMENT =							148	65	148	65
							[33]	[34]	[35]	[36]

with and without the investment in a new runway. Using Reference 3, the airport planner determines the IFR and VFR processing rates for 1979 would be 53 and 99 operations per hour for the airport without the new runway. In 1988, the fleet mix changes do not substantially alter the IFR and VRF processing rates according to Reference 3, again assuming no new runway investment. These numbers are entered onto page 1of Worksheet #2.

Calculating the IFR and VFR runway processing rates with the new runway is slightly more involved because processing rates are influenced by the direction of aircraft operations. When the wind is such that the runway intersection is near the end of the runway used at point of touchdown on landing and brake release on departure, the IFR and VFR hourly processing rate will be 71 and 175 operations per hour in 1979, according to Reference 3. If runway operations take place in the opposite direction, the runway intersection will be at the opposite end of the runway from touchdown and start of takeoff roll. In this instance Reference 3 gives the IFR and VFR processing rates to be 55 and 99 operations per hour. The analyst estimates that the runway intersection will be located near the start of runway operations 65 percent of the time (as illustrated in Figure 2), and the runway processing rates are combined on page 2 of Worksheet #2, using the assumed frequency of use percentage for each runway configuration. Therefore, in 1978, hourly IFR processing rates will be $0.65 \times 71 + 0.35 \times 55 = 65.4$ and the VFR processing rate will be $0.65 \times 175 + 0.35 \times 99 = 148.4$.

The procedure used to derive the processing rates for 1988 is the same as was illustrated for 1979 operations. It will be noticed that, in the YNG example, the 1988 processing rates are the same as those for 1979, because the projected fleet mix in 1988 is similar to that in 1979.

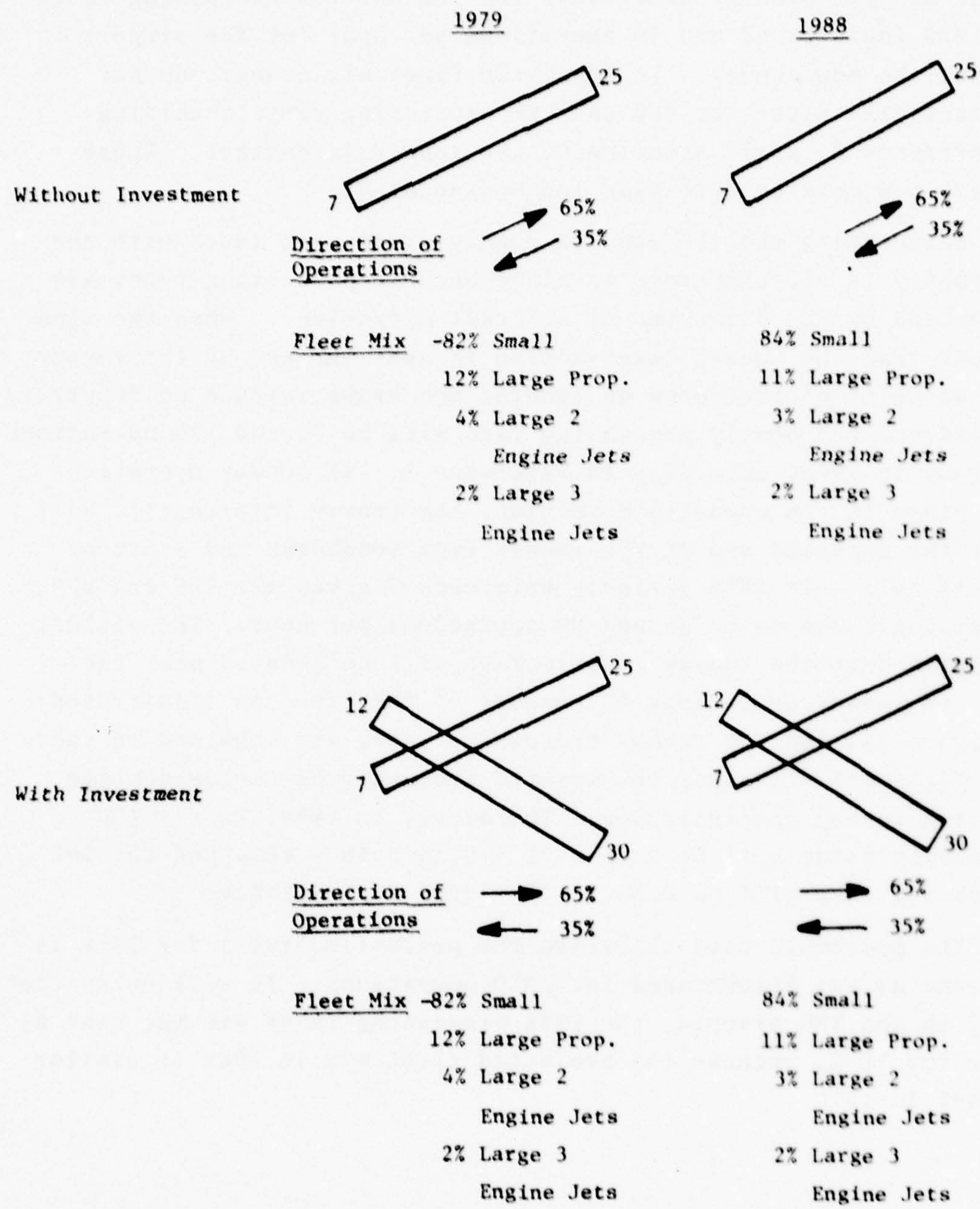

FIGURE 2. AIRPORT RUNWAY CONFIGURATIONS (SEE DISCUSSION IN SAMPLE CALCULATIONS)

3. ESTIMATE AIRPORT DELAY REDUCTION

This section of the handbook describes the method of estimating reductions in airport delay from an airport investment. The process is laid out on Worksheets #3 and #4. In Worksheet #3, the user develops measures of airport congestion with and without the investment for YEAR 1 and YEAR 10. In Worksheet #4, these measures of congestion are used to estimate the average delay per aircraft operation at the airport first without and then with the new investment. Total annual aircraft delay can then be computed for the airport for both the "Investment" and the "No Investment" scenarios, for YEAR 1 and YEAR 10.

3.1 QUANTIFY RUNWAY CONGESTION

The Airport demand, weather and processing rate information developed in Worksheets #1 and #2 are used in this section to evelop four rough measures of the airport operating environment for YEAR 1 and YEAR 10. The procedure is carried out in four steps on Worksheet #3. The steps are:

STEP 1.

First the airport's average hourly processing rate is calculated by combining the airport's IFR and VFR processing rates, using the historical frequency of occurrance for IFR and VFR weather as weighting factors. Designating the hourly IFR and VFR processing rates as P_I and P_V, and the historical relative frequency of occurance of IFR and VFR weather as f_I and f_V (where $f_I + f_V = 1.00$), the average hourly processing rate for an airport (designated as $\overline{p}$) is calculated using the relationship

$$\overline{p} = f_I \cdot P_I + f_V \cdot P_V$$

STEP 2.

The second step, calculating airport traffic intensity $\overline{\rho}$ simply uses the total volume of annual airport operations V_T and the average runway processing rate $\overline{p}$ in the relationship

$$\rho = V_T/(8760 \cdot \overline{p})$$

WORKSHEET #3: AIRPORT CONGESTION MEASURES

QUANTIFY RUNWAY CONGESTION, WITHOUT INVESTMENT

	YEAR 1	YEAR 10
STEP 1: $\bar{p} = f_I p_I + f_V p_V$		
	[27] x [30] = (11.1)	[27] x [32] = (11.1)
	+ [28] x [29] = (78.2)	+ [28] x [31] = (78.2)
	$\bar{p}$ = total = (89.3) [37]	$\bar{p}$ = total = (89.3) [38]
STEP 2: $\rho = V_T/(8760.\bar{p})$		
	$\rho = \frac{[1]\ \text{yr 1.}}{8760\cdot[37]}$	$\rho = \frac{[1]\ \text{yr 10}}{8760\cdot[38]}$
	$= \frac{(118{,}000)}{8760\cdot(89.3)}$	$= \frac{(205{,}800)}{8760\cdot(89.3)}$
	= (0.151) [39]	= (0.263) [40]
STEP 3: $r = P_I/P_V$		
	r = [30] / [29]	r = [32] / [31]
	= (53.)/(99.)	= (53.)/(99.)
	= (0.535) [41]	= (0.535) [42]
STEP 4: $\gamma = V_N/V_T$		
	γ = [5] yr 1	γ = [5] yr 10
	= (.915) [43]	= (.935) [44]

WORKSHEET #3
2/2

QUANTIFY RUNWAY CONGESTION, WITH INVESTMENT

	YEAR 1	YEAR 10
STEP 1: $\bar{p} = f_I p_I + f_V p_V$		
	[27] x [34] = (13.6)	[27] x [36] = (13.6)
	[28] x [33] = (116.9)	[28] x [35] = (116.9)
	$\bar{p}$ = total = (130.6) [45]	$\bar{p}$ = total = (130.6) [46]
STEP 2: $\rho = V_T/(8760 \cdot \bar{p})$		
	$\rho = \frac{[1]\ \text{yr 1}}{8760 \cdot [45]}$	$\rho = \frac{[1]\ \text{yr 10}}{8760 \cdot [46]}$
	$= \frac{(118{,}000)}{8760\ (130.6)}$	$= \frac{(205{,}800)}{8760\ (130.6)}$
	= (0.103) [47]	= (0.180) [48]
STEP 3: $r = P_I/P_V$		
	r = [34]/[33]	r = [36]/[35]
	= (65.)/(148.)	= (65.)/(148.)
	= (0.439) [49]	= (0.439) [50]
STEP 4: $\gamma = V_N/V_T$		
	γ = [5] yr 1	γ = [5] yr 10
	= (0.915) [51]	= (0.935) [52]

$\bar{\rho}$ designates the total annual rate of operation divided by the maximum possible number of runway operations for the year (average processing rates times the number of hours per year).

STEP 3.

The ratio of IFR processing rate to the VFR processing rate for the airport is designated as r. The value for r is determined directly from the average IFR and VFR processing rates P_I and P_V, previously developed as follows

$$r = P_I \ / \ P_V$$

STEP 4.

The fraction of total airport operations made by nonscheduled aircraft is designated by the symbol γ. For each year being considered, γ is determined using the projection of total scheduled and nonscheduled operations V_S and V_N as follows:

$$\gamma = V_N \ / \left(V_S + V_N\right) = V_N / V_T$$

These three terms, $\bar{\rho}$, r and γ are important determinants of airport runway delay, and are used in estimating the level of runway delay for the airport being evaluated.

3.2 DETERMINE CHANGES IN AVERAGE RUNWAY DELAY

The handbook user will estimate airport runway delays using Worksheet #4 and the graphs at the end of this section. These groups give average arrival and departure delay as a function of $\bar{\rho}$, r and γ. Airports differ in their delay characteristics because of weather and level of activity, so this handbook contains arrival and departure delay graphs for 24 different airport types. Table 9 indicates the proper pair of graphs to be used for different airport categories. Separate graphs are contained in this handbook for airports with different scheduled volume and IFR weather frequencies, as shown by the first two columns of Table 9. In addition, separate graphs are presented for different values of r, the ratio of IFR to VRF runway processing rates.

WORKSHEET #4: RUNWAY DELAY REDUCTIONS

	YEAR 1	YEAR 10
WITHOUT INVESTMENT	V_s = [2] = (10,000)	V_s = [2] = (13,400)
	f_v = [28] = (.79)	f_v = [28] = (.79)
	r = [41] = (.535)	r = [42] = (.535)
	Figures 8.1 and 8.2	Figures 8.1 and 8.2
	γ = [43] = (.915)	γ = [44] = (.935)
	ρ = [39] = (.151)	ρ = [40] = (.263)
	Arr Delay = (.35) [53] min/operation	Arr Delay = (1.70) [54] min/operation
	Dep Delay = (.42) [55] min/operation	Dep Delay = (2.1) [56] min/operation
WITH INVESTMENT	V_s = [2] = (10,000)	V_s = [2] = (13,400)
	f_v = [28] = (.790)	f_v = [28] = (.79)
	r = [49] = (.439)	r = [50] = (.439)
	Figures 9.1 and 9.2	Figures 9.1 and 9.2
	γ = [51] = (.915)	γ = [52] = (.935)
	ρ = [47] = (.103)	ρ = [48] = (.180)
	Arr Delay = (.19) [57] min/operation	Arr Delay = (.70) [58] min/operation
	Dep Delay = (.23) [59] min/operation	Dep Delay = (.69) [60] min/operation

WORKSHEET #4
2/3

DELAY REDUCTION PER OPERATION

YEAR 1	YEAR 10
Arrival Delay	Arrival Delay
Reduction/Operation	Reduction/Operation
= [53] - [57]	= [54] - [58]
= (0.35)	= (1.70)
- (0.19)	- (0.70)
= (0.16)	= (1.00)
[61] min/operation	[62] min/operation
Departure Delay	Departure Delay
Reduction/Operation	Reduction/Operation
= [55] - [59]	= [56] - [60]
= (0.42)	= (2.10)
- (0.23)	- (0.69)
= (0.19)	= (1.41)
[63] min/operation	[64] min/operation

ANNUAL DELAY REDUCTION

YEAR 1	YEAR 10
Arrival Delay Reduction/Year	Arrival Delay Reduction/Year
$= \frac{1}{120}$ [61] x [1] yr 1	$= \frac{1}{120}$ [62] x [1] yr 10
= (.0013)	= (.0083)
x (118,000)	x (205,000)
L = (157.3) [65] acft hr/yr	L = (1,715.) [66] acft hr/yr
Departure Delay Reduction/Year	Departure Delay Reduction/Year
$= \frac{1}{120}$ [63] x [1] yr 1	$= \frac{1}{120}$ [64] x [1] yr 10
= (.0015)	= (.0118)
(118,000)	(205,000)
T = (186.8) = [67] acft hr/yr	T = (2,418.) = [68] acft hr/yr
TOTAL = [65] + [67]	= [66] + [68]
= (344.1) [69] acft hr/yr	= (4,133.) [70] acft hr/yr

TABLE 9. AIRPORT CATEGORIES FOR ESTIMATION OF RUNWAY DELAYS

IF ANNUAL SCHEDULED VOLUME V_S IS BETWEEN	FREQUENCY f_V OF VFR WEATHER IS BETWEEN	AND RATIO P_I/P_V OF IFR TO VFR PROCESSING RATE IS	USE RUNWAY DELAY GRAPH IN FIGURE NO
0-100,000	84% - 100%	0.7 - 1.0	4
		0.5 - 0.69	5
		0.3 - 0.49	6
0-100,000	<84%	0.7 - 1.0	7
		0.5 - 0.69	8
		0.3 - 0.49	9
100,000-200,000	89% - 100%	0.7 - 1.0	10
		0.5 - 0.69	11
		0.3 - 0.49	12
100,000-200,000	84% - 89%	0.7 - 1.0	13
		0.5 - 0.69	14
		0.3 - 0.49	15
100,000-200,000	<84%	0.7 - 1.0	16
		0.5 - 0.69	17
		0.3 - 0.49	18
>200,000	89% - 100%	0.7 - 1.0	10
		0.5 - 0.69	11
		0.3 - 0.49	12
>200,000	84% - 89%	0.7 - 1.0	19
		0.5 - 0.69	20
		0.3 - 0.49	21
>200,000	<84%	0.7 - 1.0	22
		0.5 - 0.69	23
		0.3 - 0.49	24

Once the proper pair of delay graphs has been located, the handbook user develops estimates of runway arrival and departure delays directly from the graphs simply by using the appropriate value of γ and ρ, and reading the resulting values of runway delay directly from the graphs. Worksheet #4 provides space to enter the graph-selection parameters V_s, f_v, r, to note the corresponding figure from Table 9, and to enter the arrival and departure delay read off the two graphs of the figure. Runway delay reductions are then calculated on the next page of the Worksheet. Finally, on the third page of the Worksheet, the user multiplies these runway delay reductions by annual arrivals and departures (from Worksheet #1) to obtain total annual delay reduction in aircraft hours per year. The factor 1/120 converts minutes to hours and annual operations to annual arrivals (or to departures).

3.3 SAMPLE CALCULATION: AIRPORT CONGESTION MEASURES

The runway congestion measures for YNG are developed on Worksheet #3, based on the previous results. The first page of the Worksheet #3 is devoted to congestion measures without the investment, and the second page to congestion measures with the investment. The following steps are carried out on each page for YEAR 1 and for YEAR 10.

STEP 1.

The average processing rate $\overline{p}$ is obtained by multiplying the VFR and IFR processing rates from Worksheet #2 by the weather frequencies from Worksheet #1.

STEP 2.

The total operations for YEAR 1 and for YEAR 10 are divided by the respective average processing rates calculated in STEP 1, to yield the traffic intensity factor ρ, entered in items (39.) and (40.).

STEP 3.

The ratio r of IFR to VFR processing rates is calculated from Worksheet #2 data for YEAR 1 and YEAR 10.

STEP 4.

The nonscheduled traffic fraction γ, is transcribed from Worksheet #1.

The four steps above are now repeated on page 2 of Worksheet #3 for conditions with the investment in place. It is seen that with the investment in place the average processing rate increases from 89 per hour to 131 per hour and the traffic intensity factor drops by about 33 percent.

3.4 SAMPLE CALCULATION: RUNWAY DELAY REDUCTIONS

Having developed the measures of runway congestion on Worksheet #3, the analyst is prepared to estimate the actual departure and arrival delays at YNG for 1979 and 1988. He first transcribes the three quantities V_s, f_v and r onto Worksheet #4, for YEAR 1 and 10, without the investment and with the investment. Using these three values, he then selects the proper figure number from Table 9. These figures appear in pairs, one for departure delay and one for arrival delay.

In order to extract delays from the figures, two congestion measures γ and ρ from Worksheet #3 are needed for each figure. The value of γ is located on the horizontal axis and the curve corresponding to the appropriate value of ρ is selected. The departure or arrival delay in minutes per operation is read off the vertical axis of the figure.

In selecting the curve to correspond to ρ, it is necessary to interpolate between values of ρ. For example, it is seen from item (39.) on Worksheet #4, that ρ for YEAR 1, without investment, is about .15. This is mid-way between the curves for ρ=.10 and ρ=.20 on Figure 8. Hence a curve for ρ=.15 may be sketched midway between those for ρ=.10 and ρ=.20, as shown in Figure 3.1 which is a copy of Figure 8. The departure delay is read from the sketched curve. (Note that the inserted curve is 5/10 of the distance from the ρ=.10 to ρ=.20 curves, as measured by a linear scale rather than by the logarithmic scale of the figure). The arrival delay is similarly read off Figure 3.2 for the same value of ρ and γ.

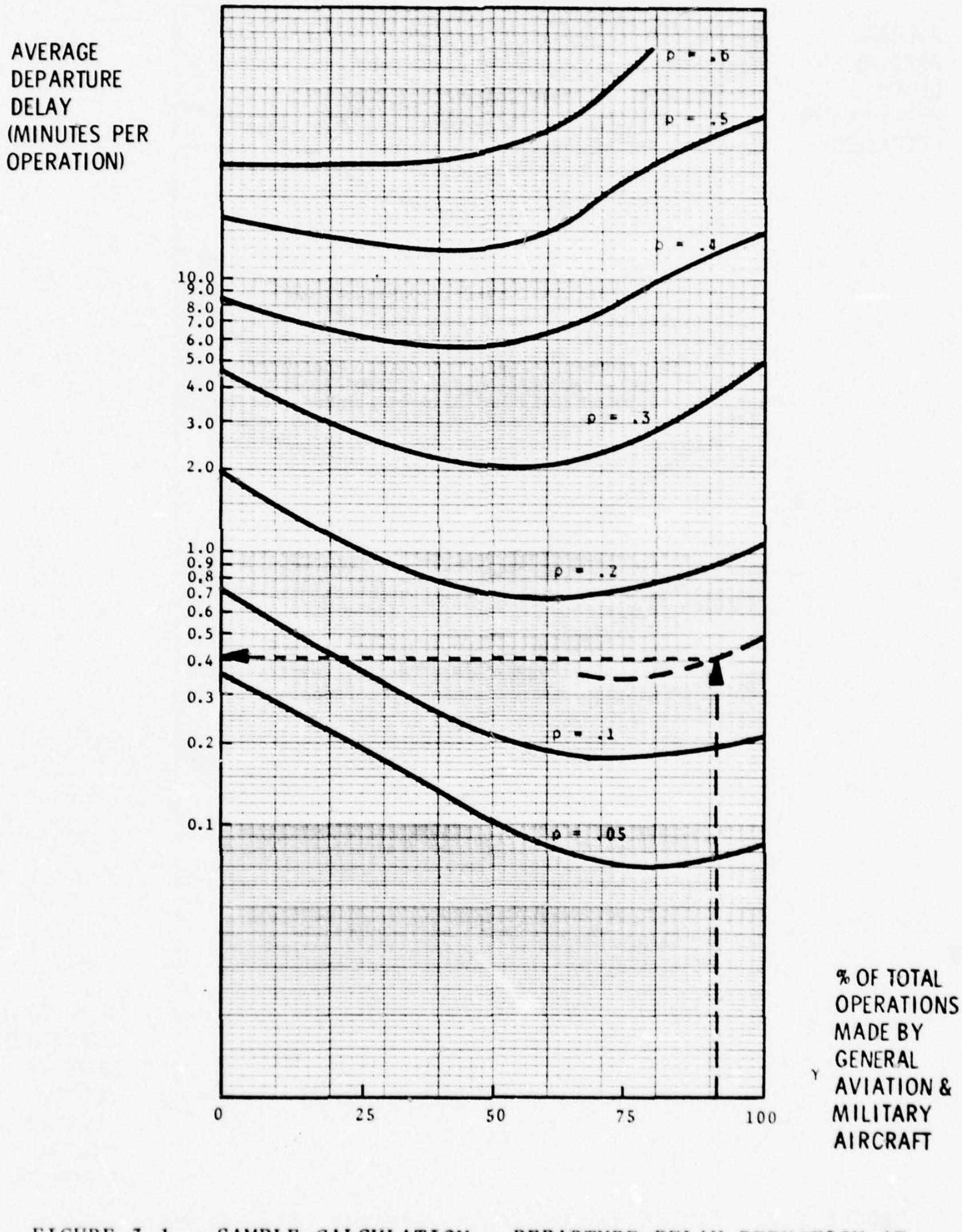

FIGURE 3.1. SAMPLE CALCULATION - DEPARTURE DELAY REDUCTION AT YNG

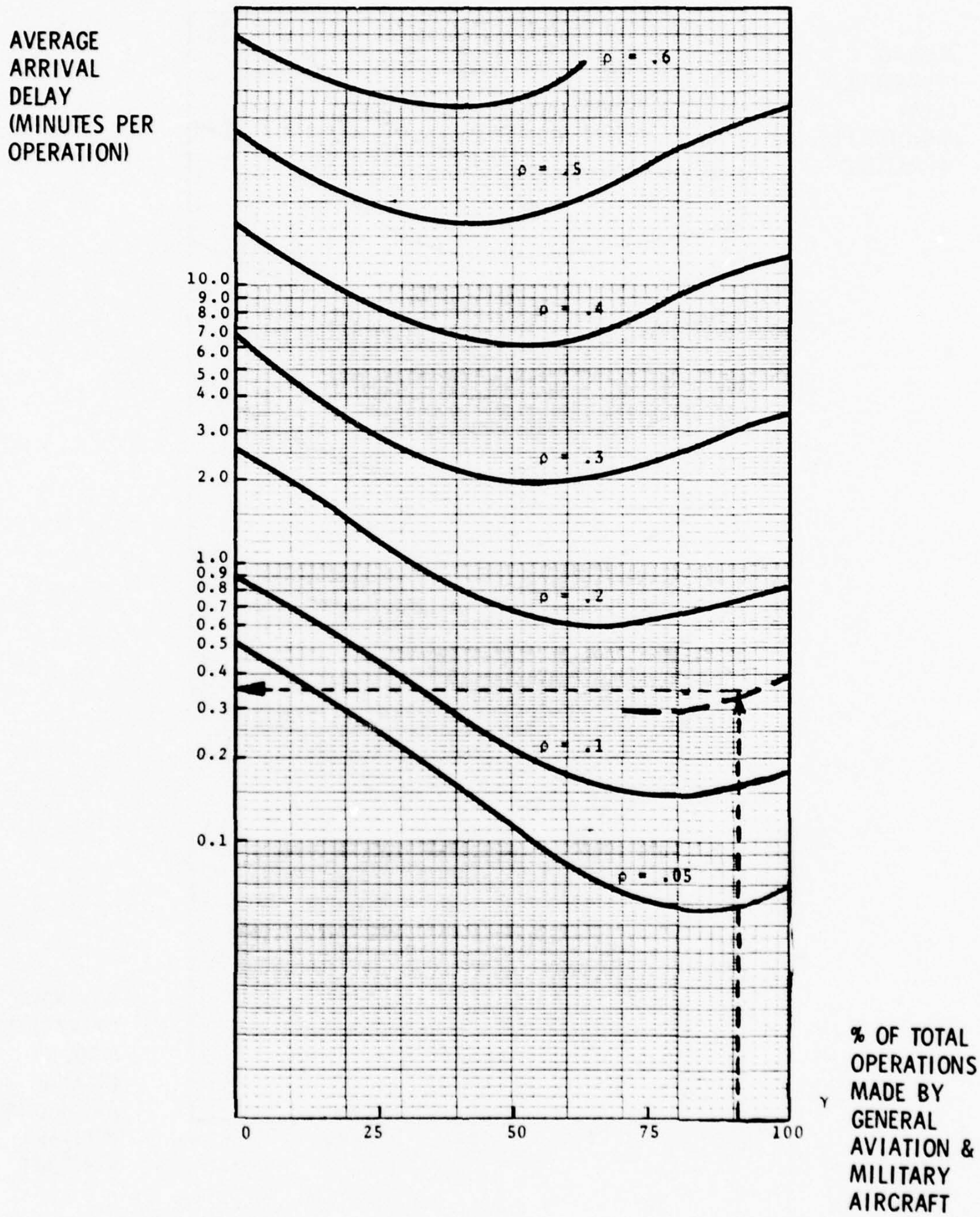

FIGURE 3.2. SAMPLE CALCULATION - ARRIVAL DELAY REDUCTION AT YNG

If the required value of ρ is .18, as in item (48.) for YEAR 10, with investment, then the inserted curve should be located 8/10 of the distance from the curve for ρ=.10 to the curve for ρ=.20 in Figure 9. Similar intermediate curves have been selected for the other cases of ρ=.26 and ρ=.10 in Figures 8. and 9. and the resultant arrival and departure delays per operation entered onto page 2 of Worksheet #4.

The delay reductions per operation are calculated on page 2 of Worksheet #4. It can be seen that arrival delay reductions due to the hypothetical investment at YNG would be .16 minutes and .19 minutes in 1979 and 1.0 minutes and 1.4 minutes in 1988. The larger delay reductions in 1988 are due to the projected increase in traffic.

Finally, the annual delay reductions are obtained on page 3 of Worksheet #4, by multiplying the delays per operation by annual operations in the four cases. These annual reductions, in aircraft hours, are labelled L and T for use in the next step.

RUNWAY DELAY CHARACTERISTICS

FIGURES 4.1 THROUGH 24.2

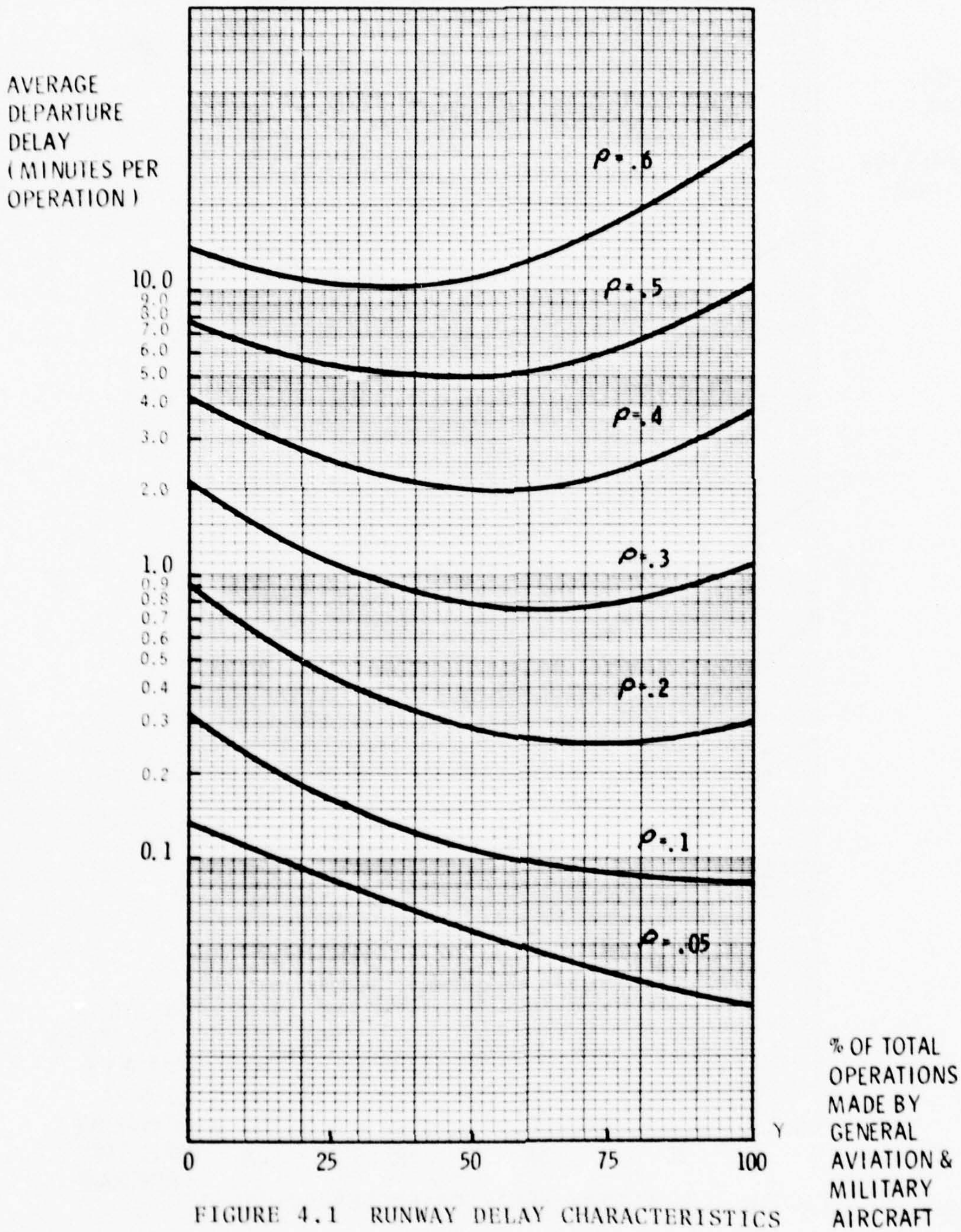

FIGURE 4.1 RUNWAY DELAY CHARACTERISTICS

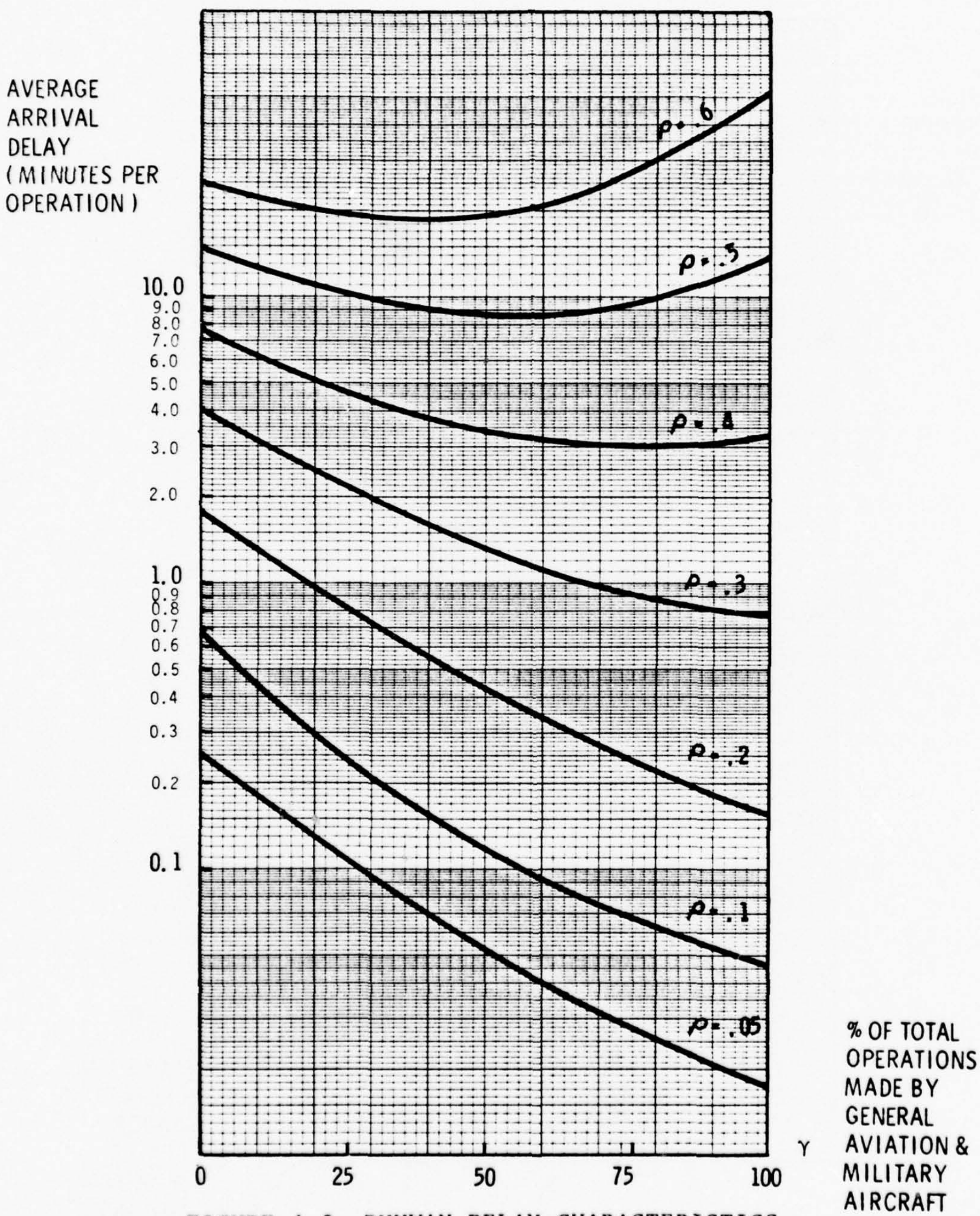

FIGURE 4.2 RUNWAY DELAY CHARACTERISTICS

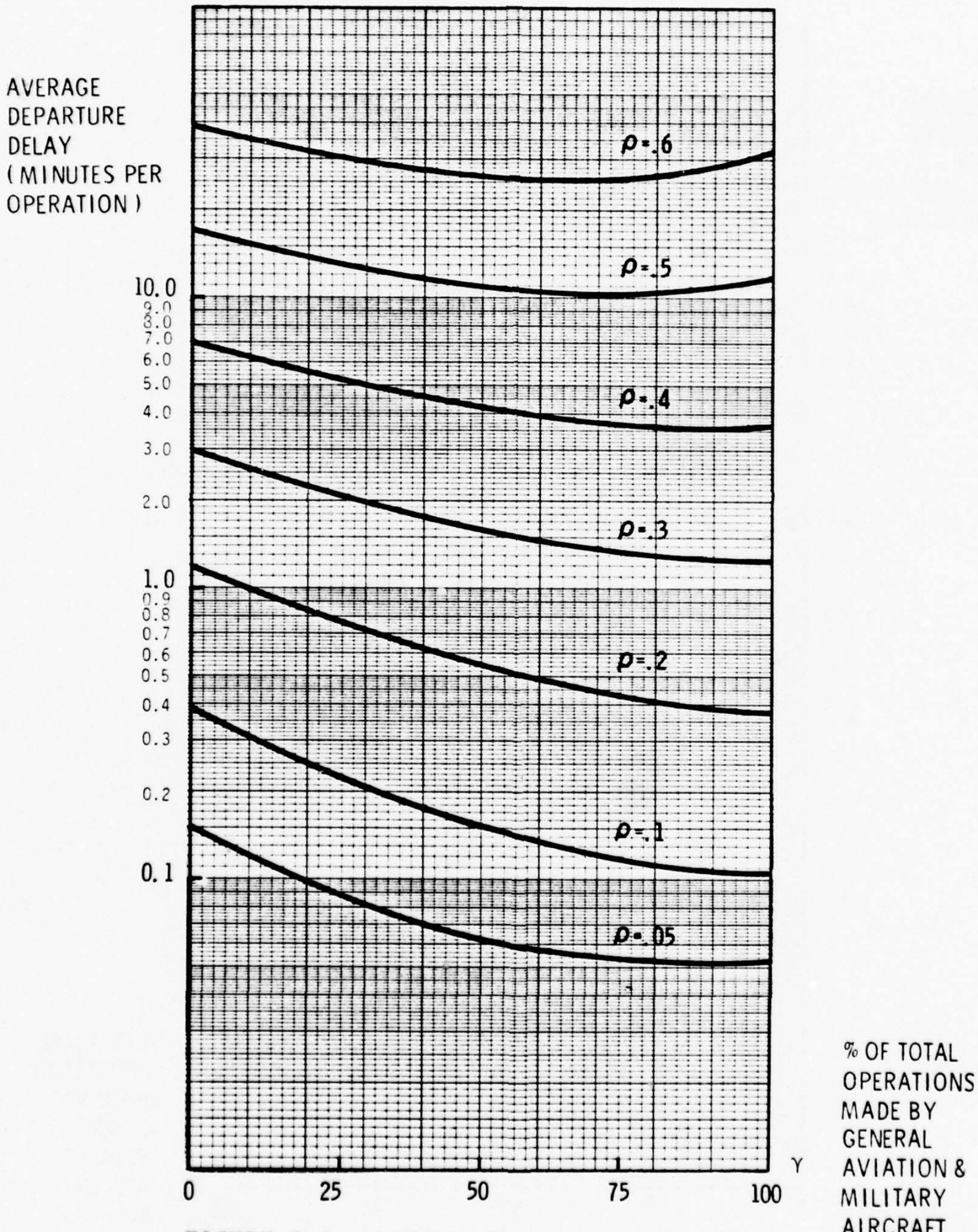

FIGURE 5.1 RUNWAY DELAY CHARACTERISTICS

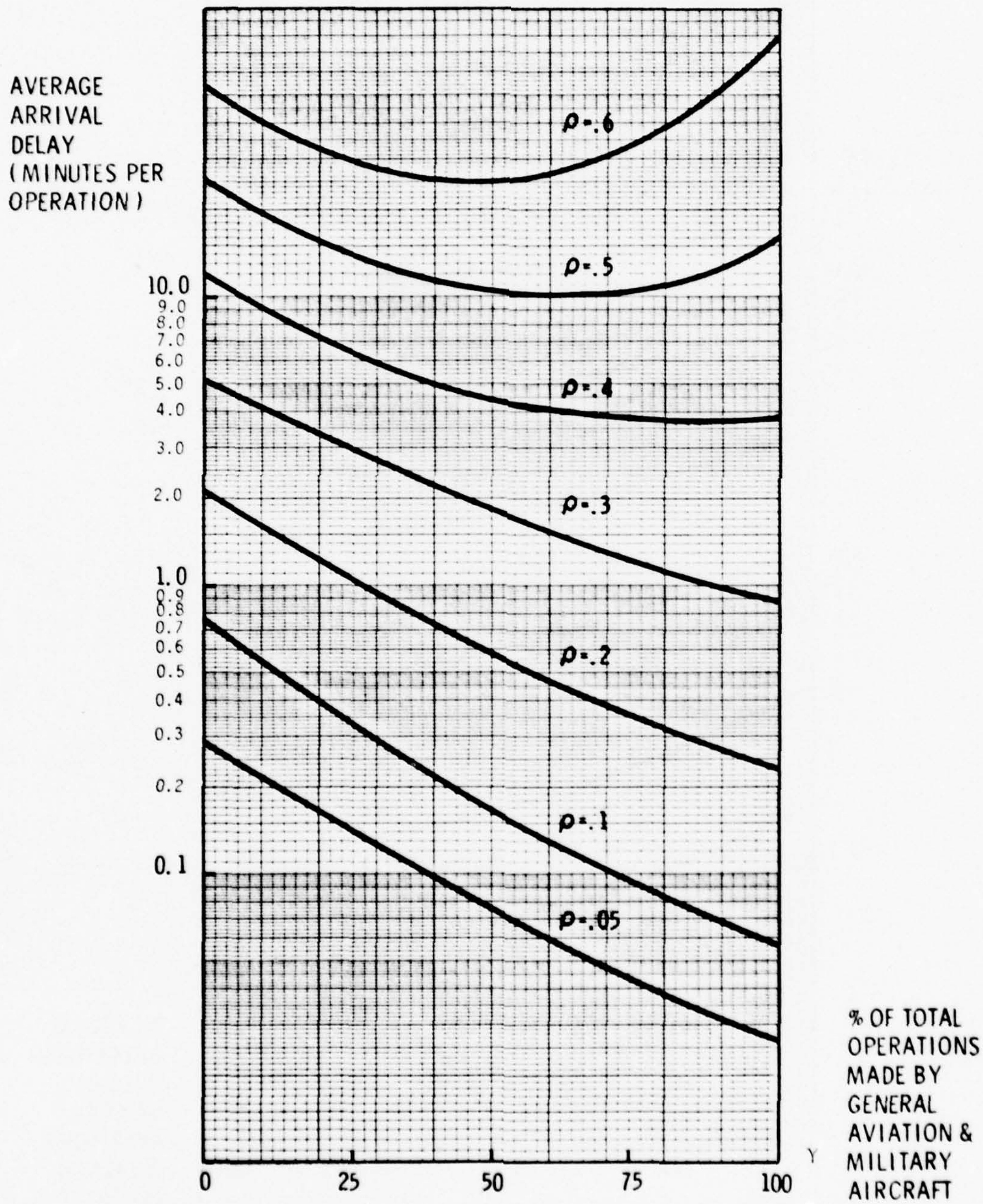

FIGURE 5.2 RUNWAY DELAY CHARACTERISTICS

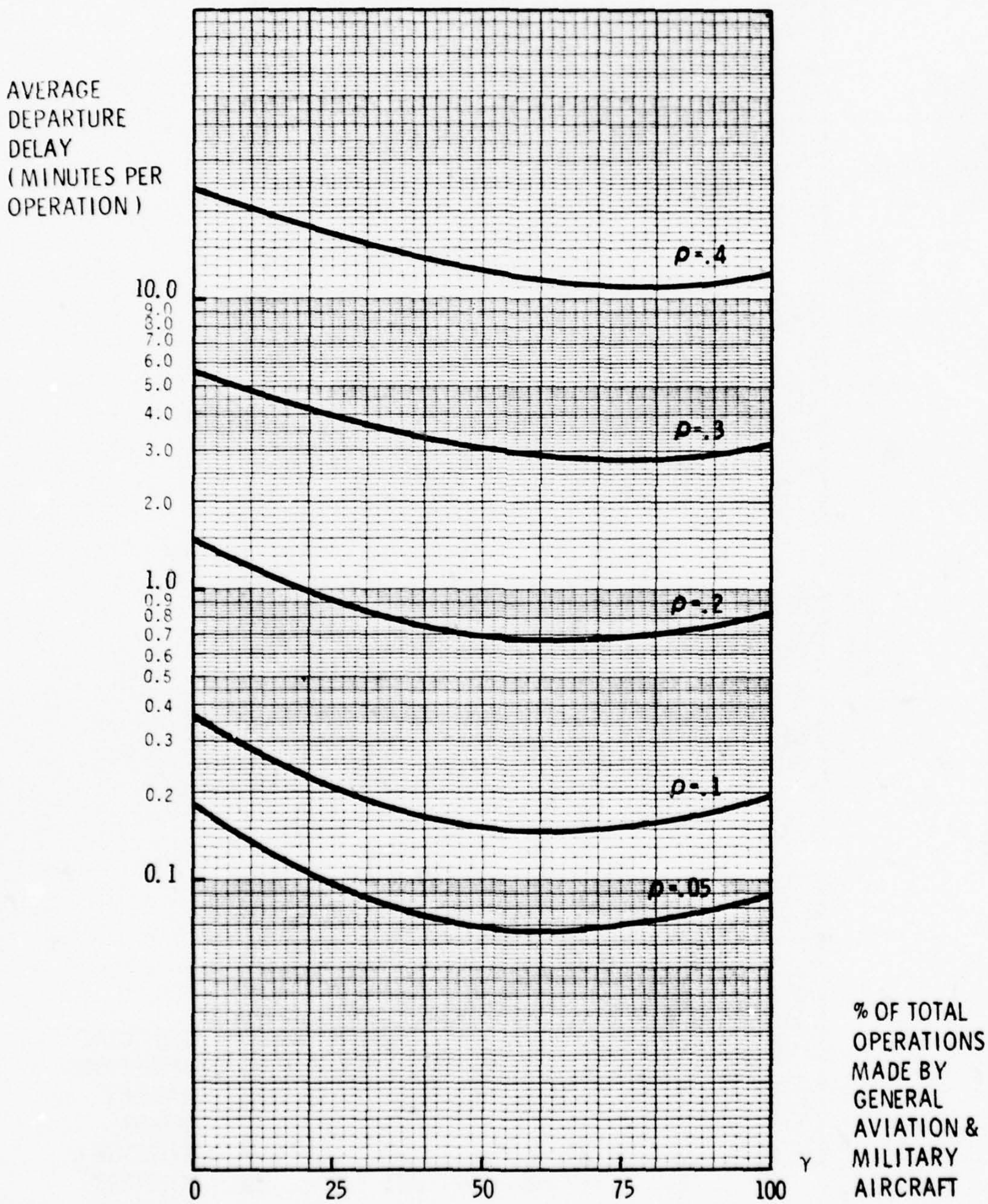

FIGURE 6.1 RUNWAY DELAY CHARACTERISTICS

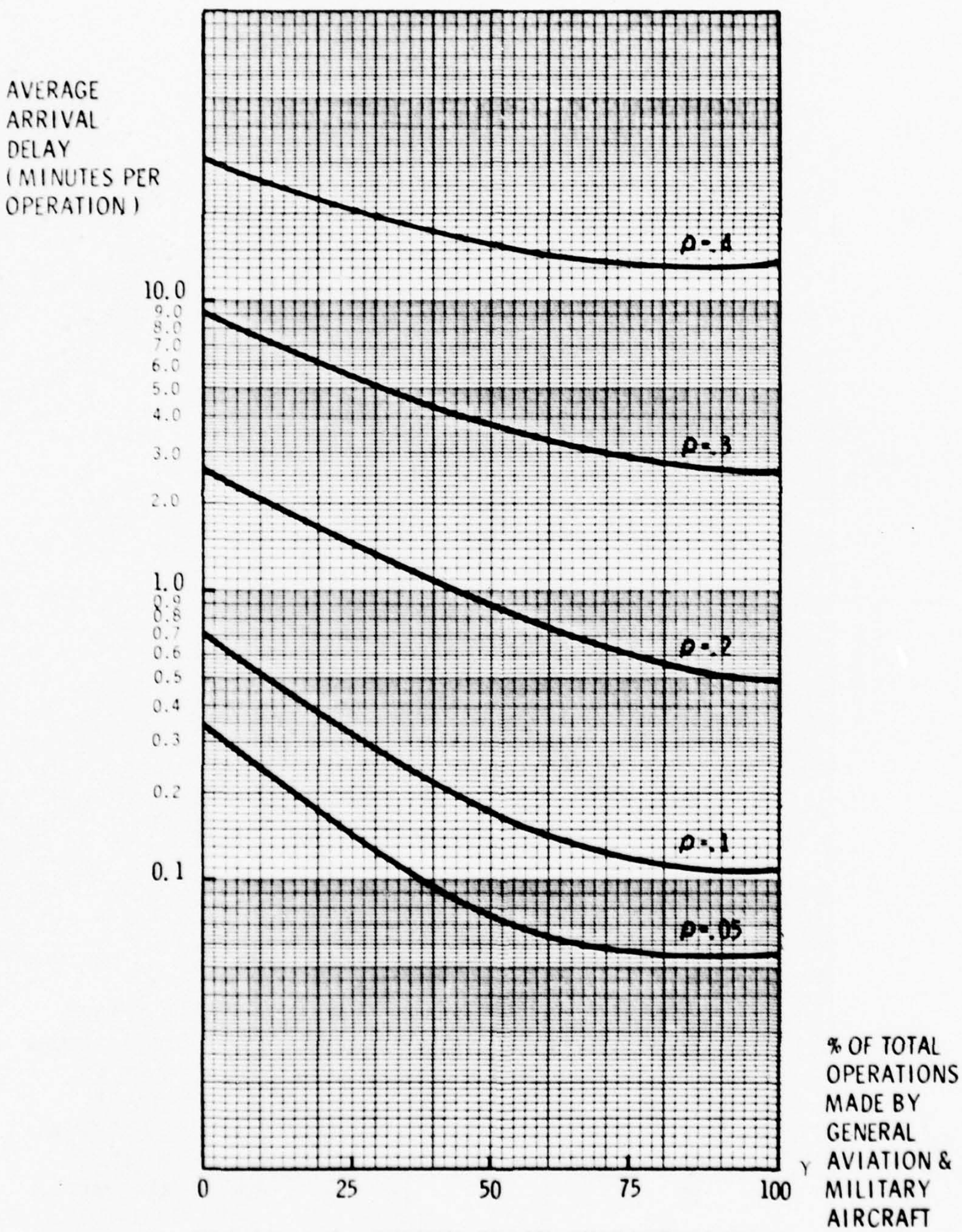

FIGURE 6.2 RUNWAY DELAY CHARACTERISTICS

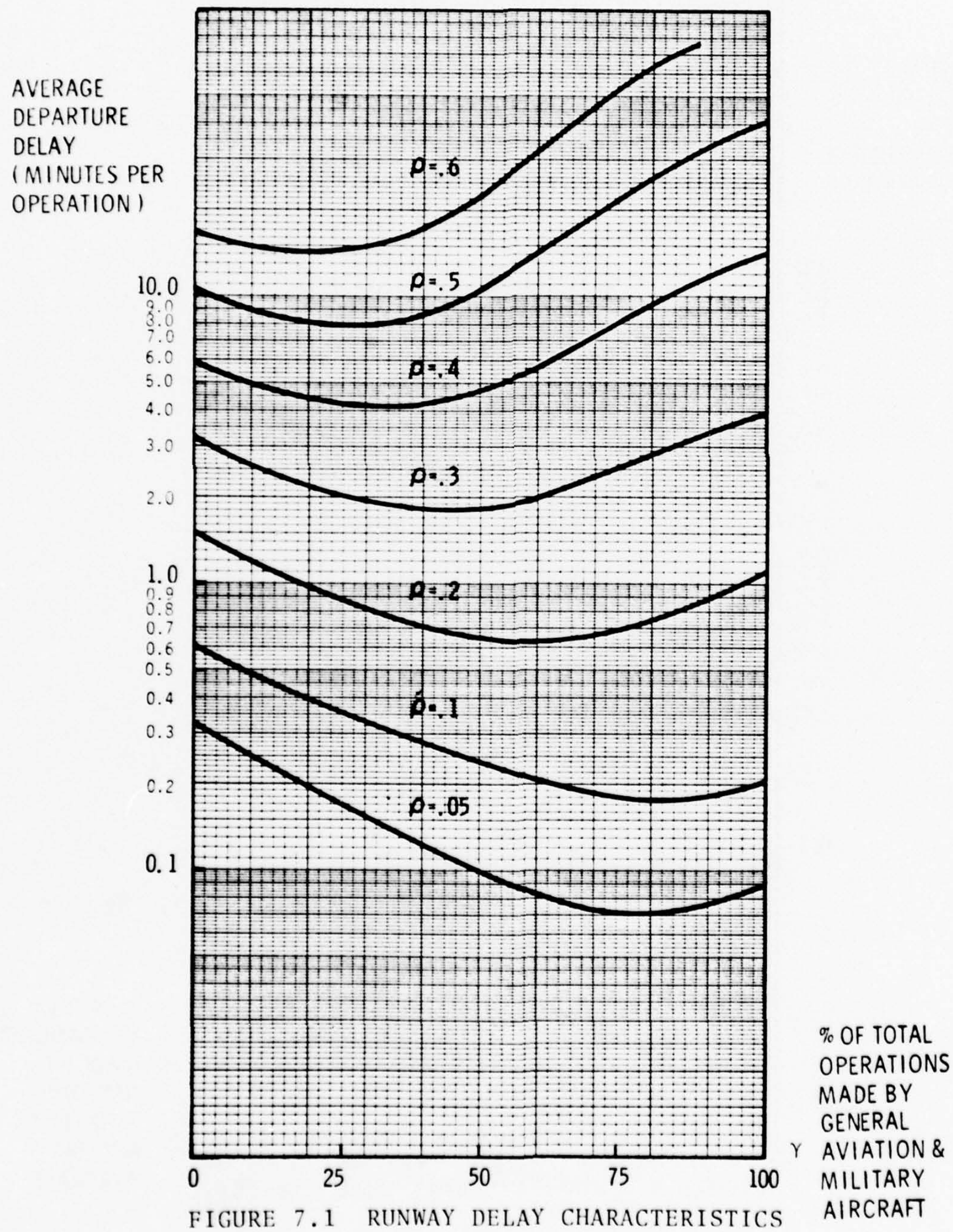

FIGURE 7.1 RUNWAY DELAY CHARACTERISTICS

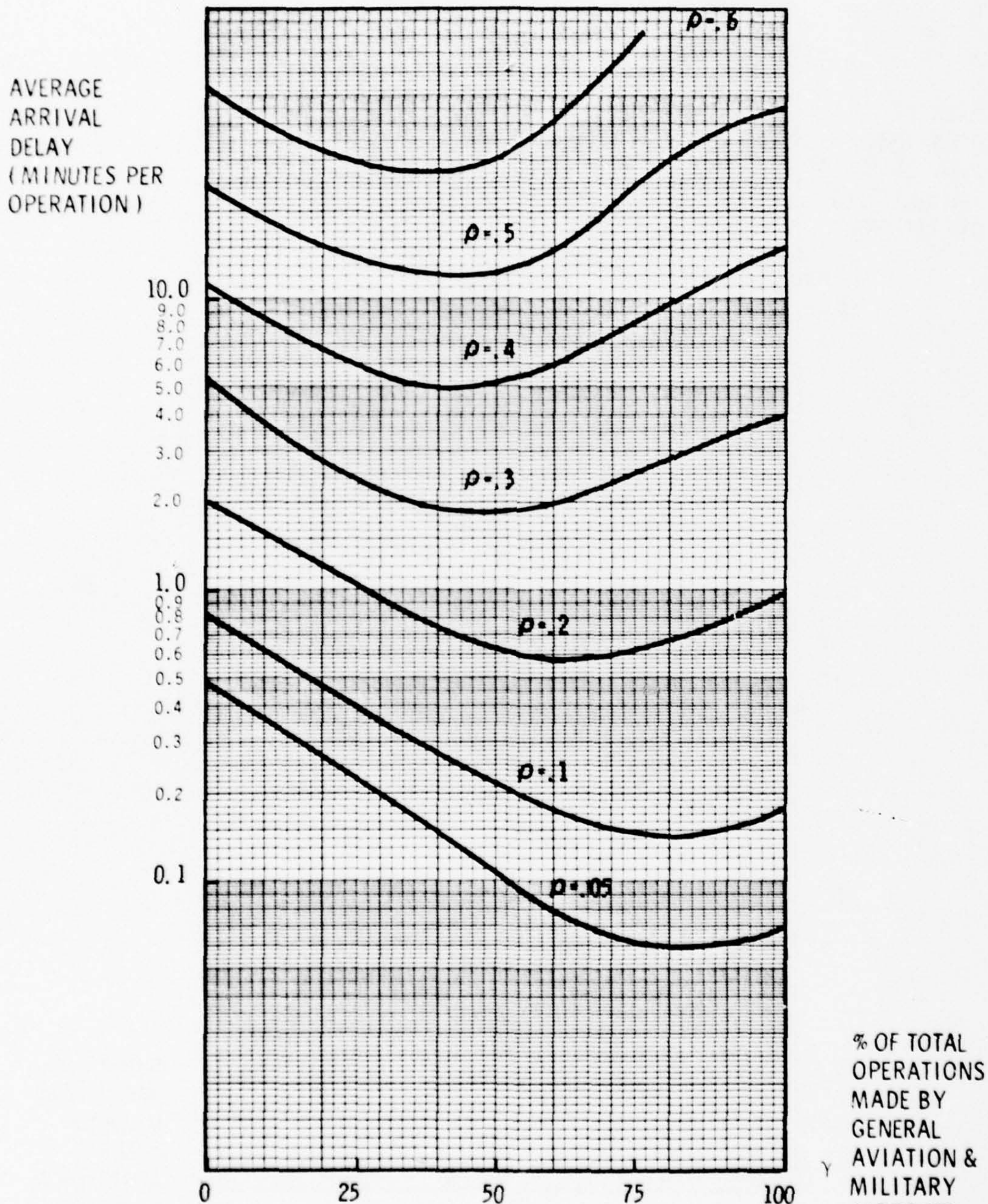

FIGURE 7.2 RUNWAY DELAY CHARACTERISTICS

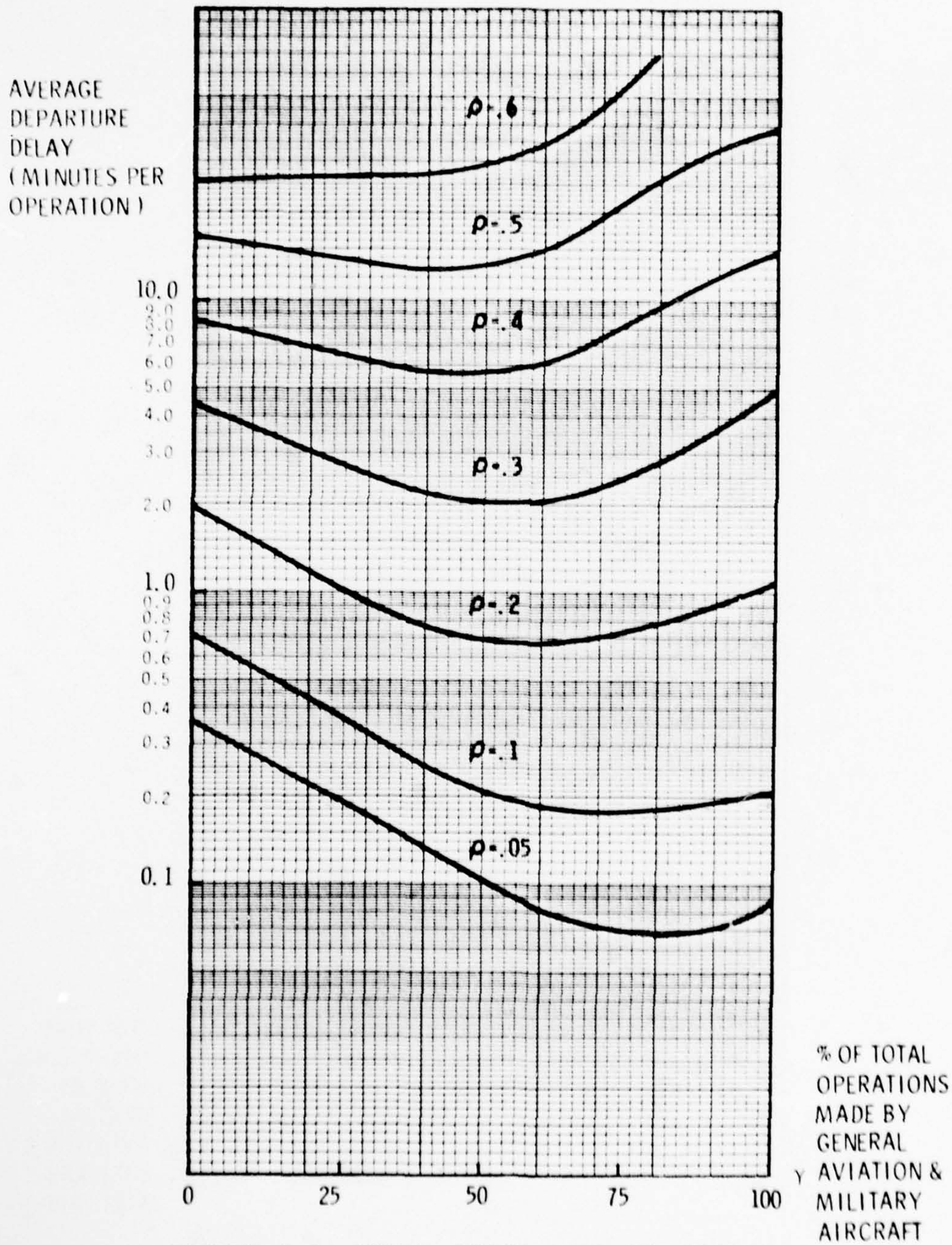

FIGURE 8.1 RUNWAY DELAY CHARACTERISTICS

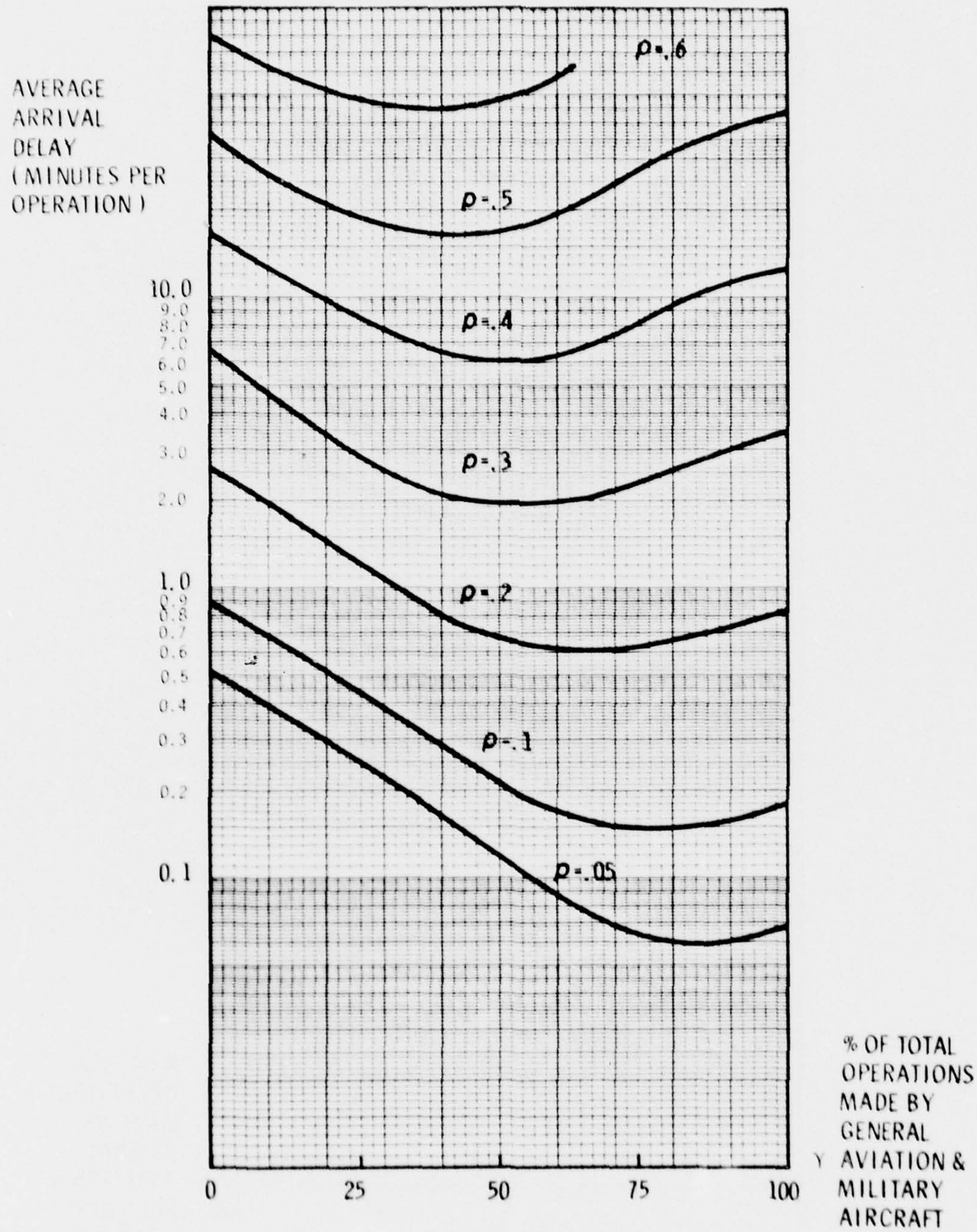

FIGURE 8.2 RUNWAY DELAY CHARACTERISTICS

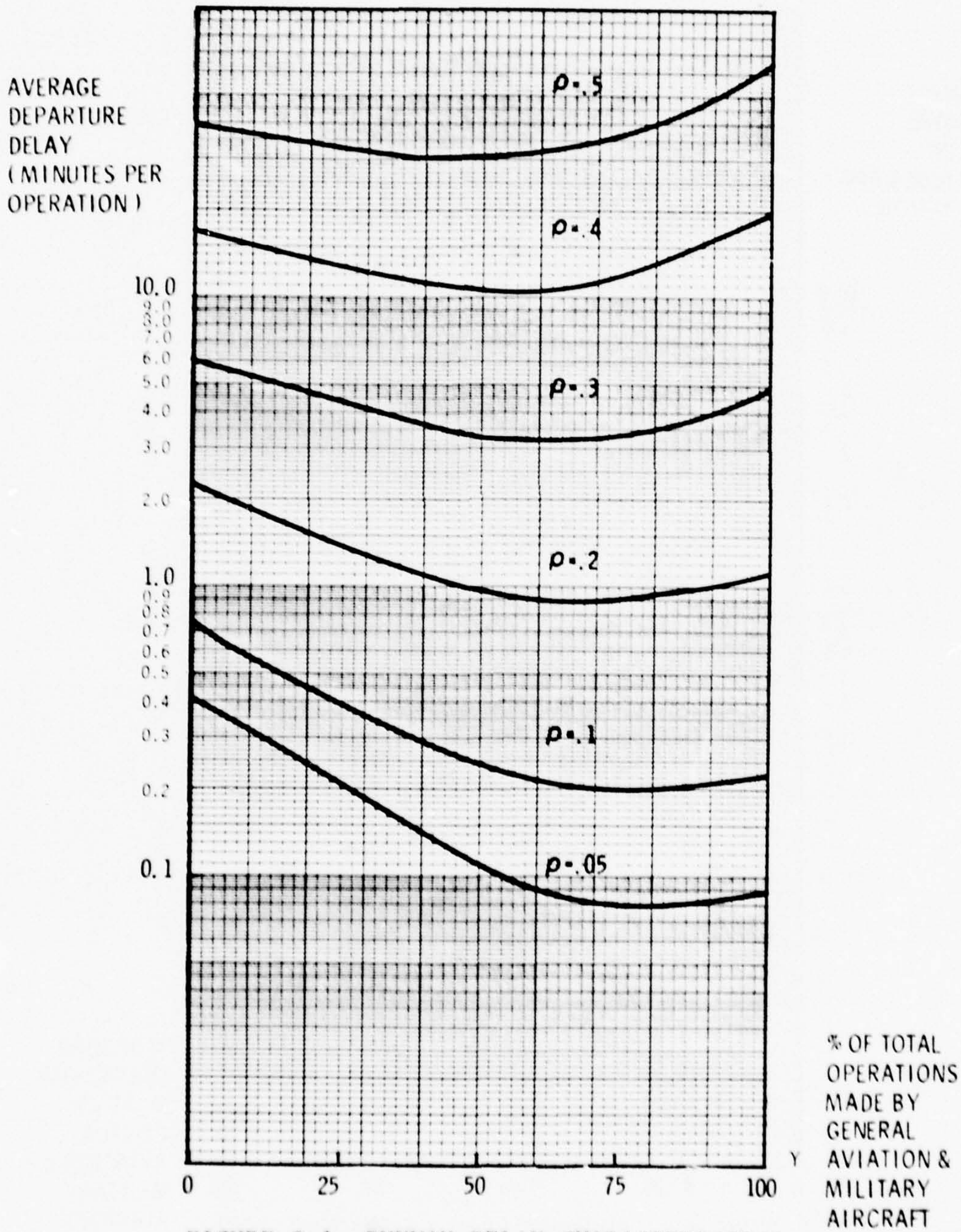

FIGURE 9.1 RUNWAY DELAY CHARACTERISTICS

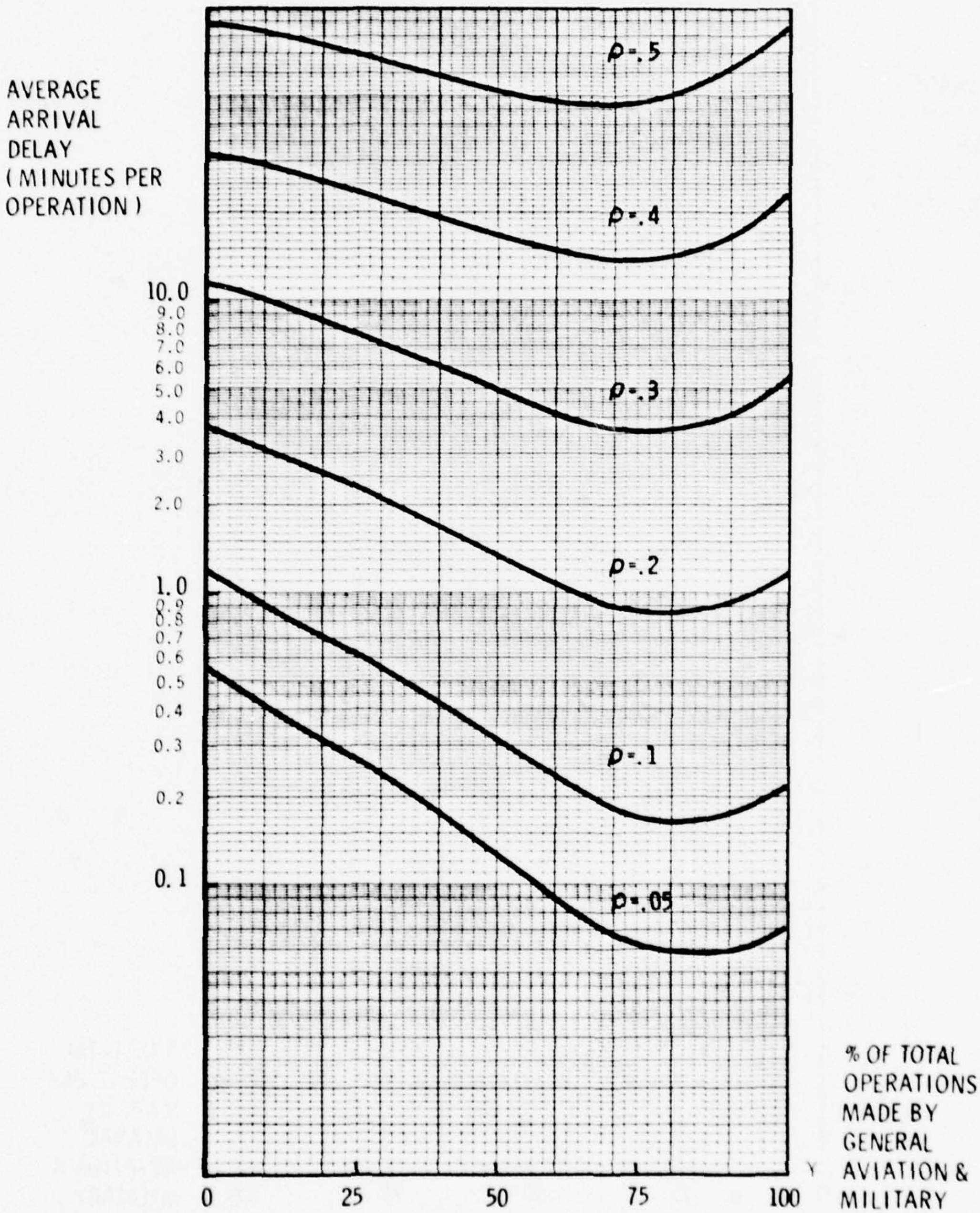

FIGURE 9.2 RUNWAY DELAY CHARACTERISTICS

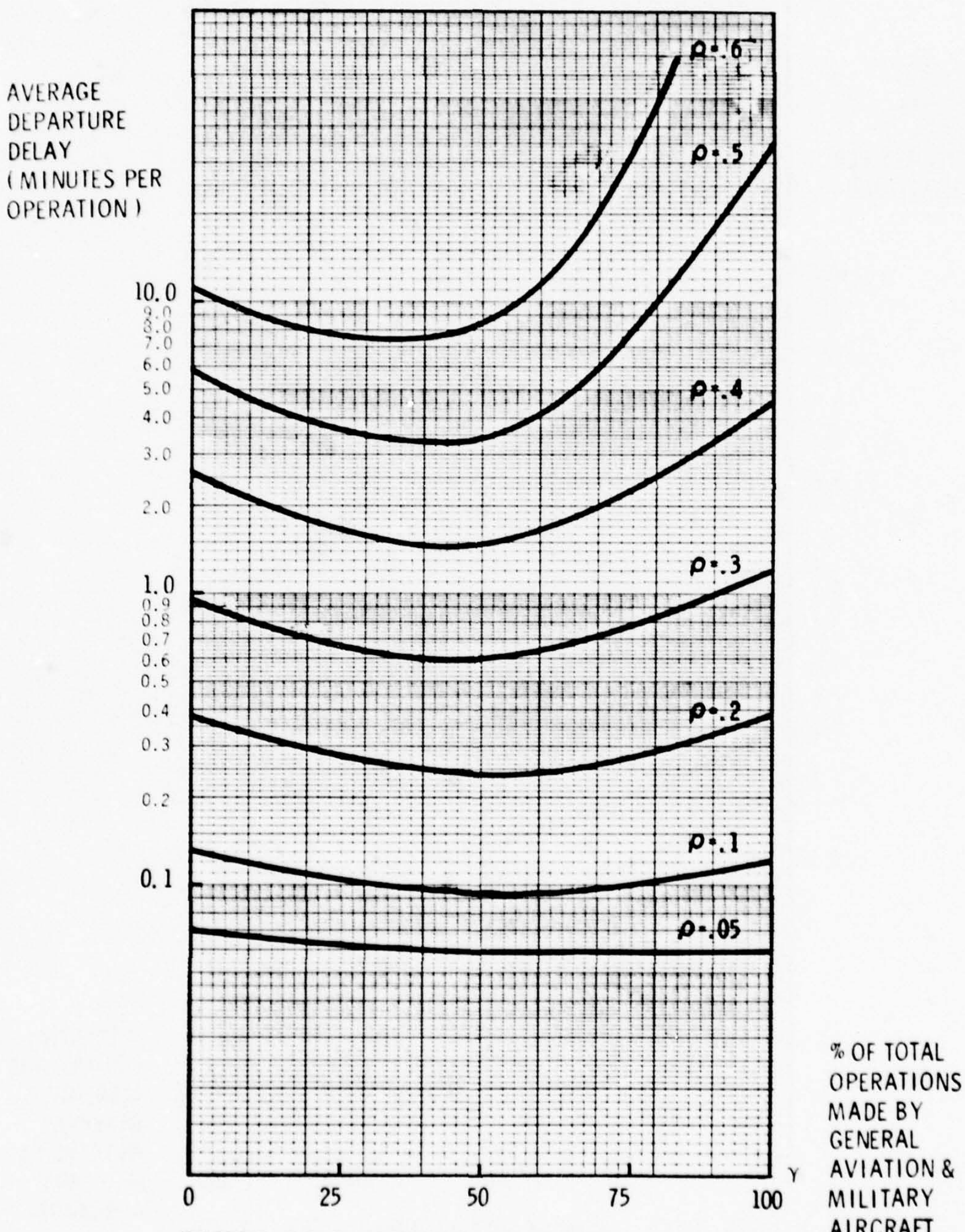

FIGURE 10.1 RUNWAY DELAY CHARACTERISTICS

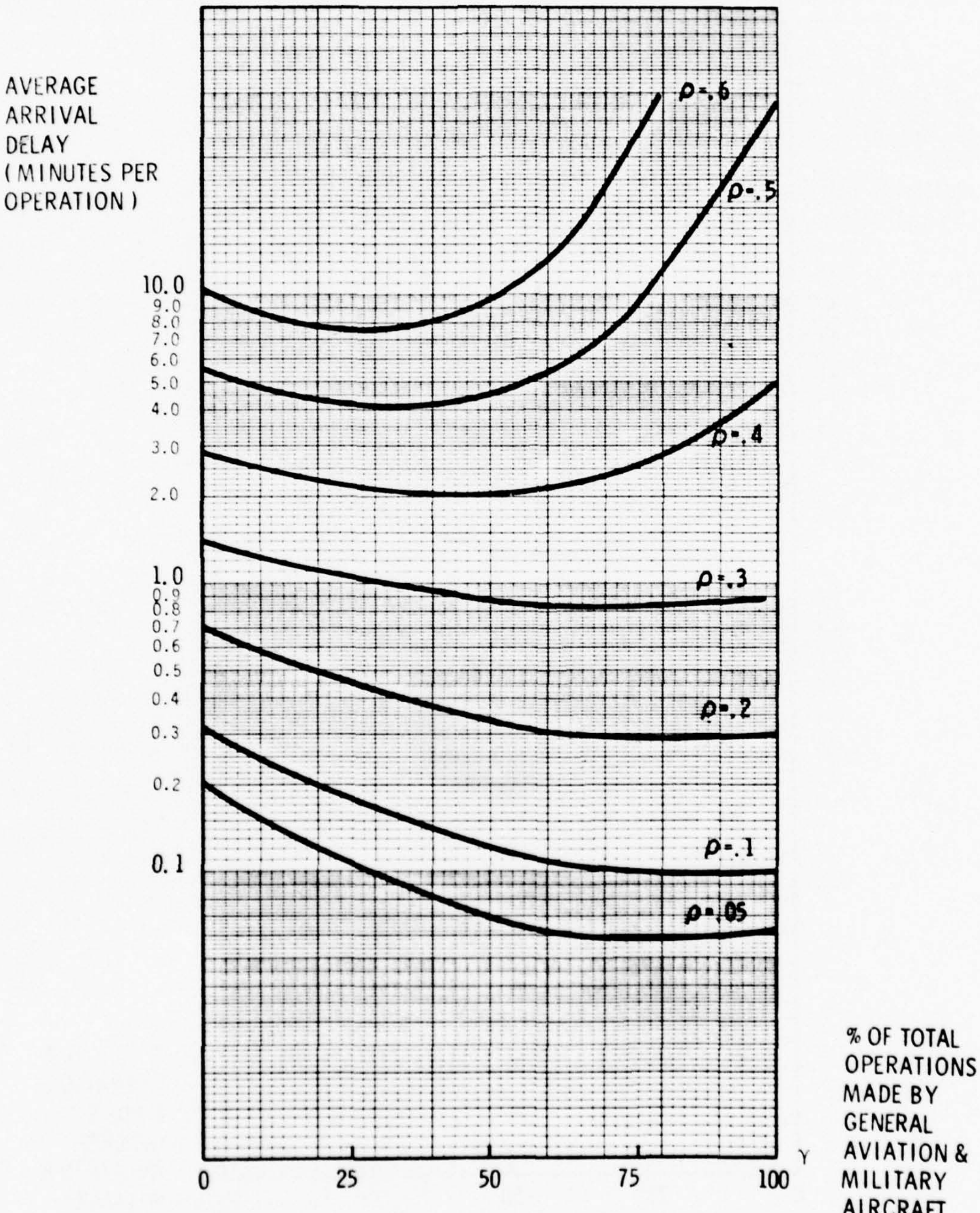

FIGURE 10.2 RUNWAY DELAY CHARACTERISTICS

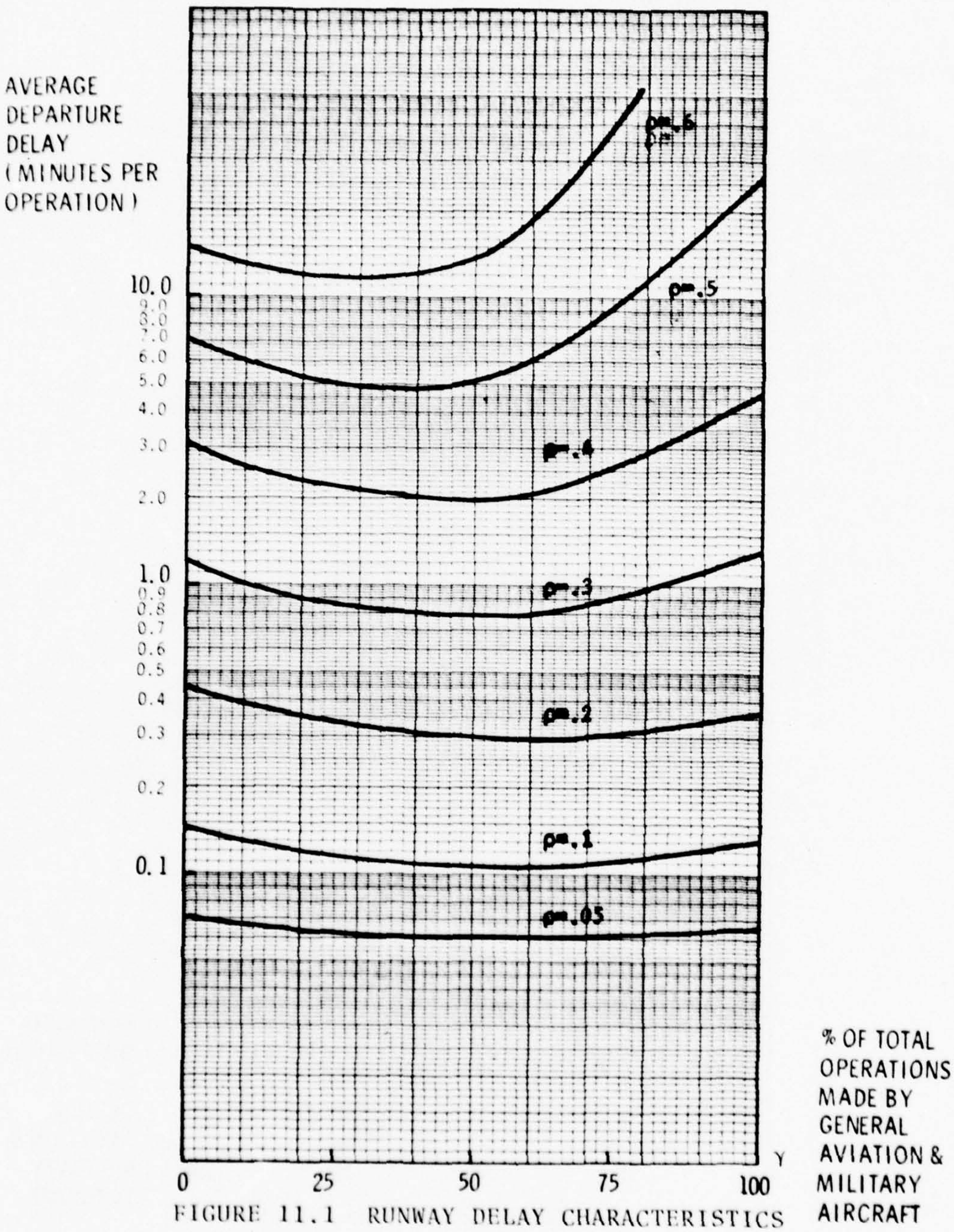

FIGURE 11.1 RUNWAY DELAY CHARACTERISTICS

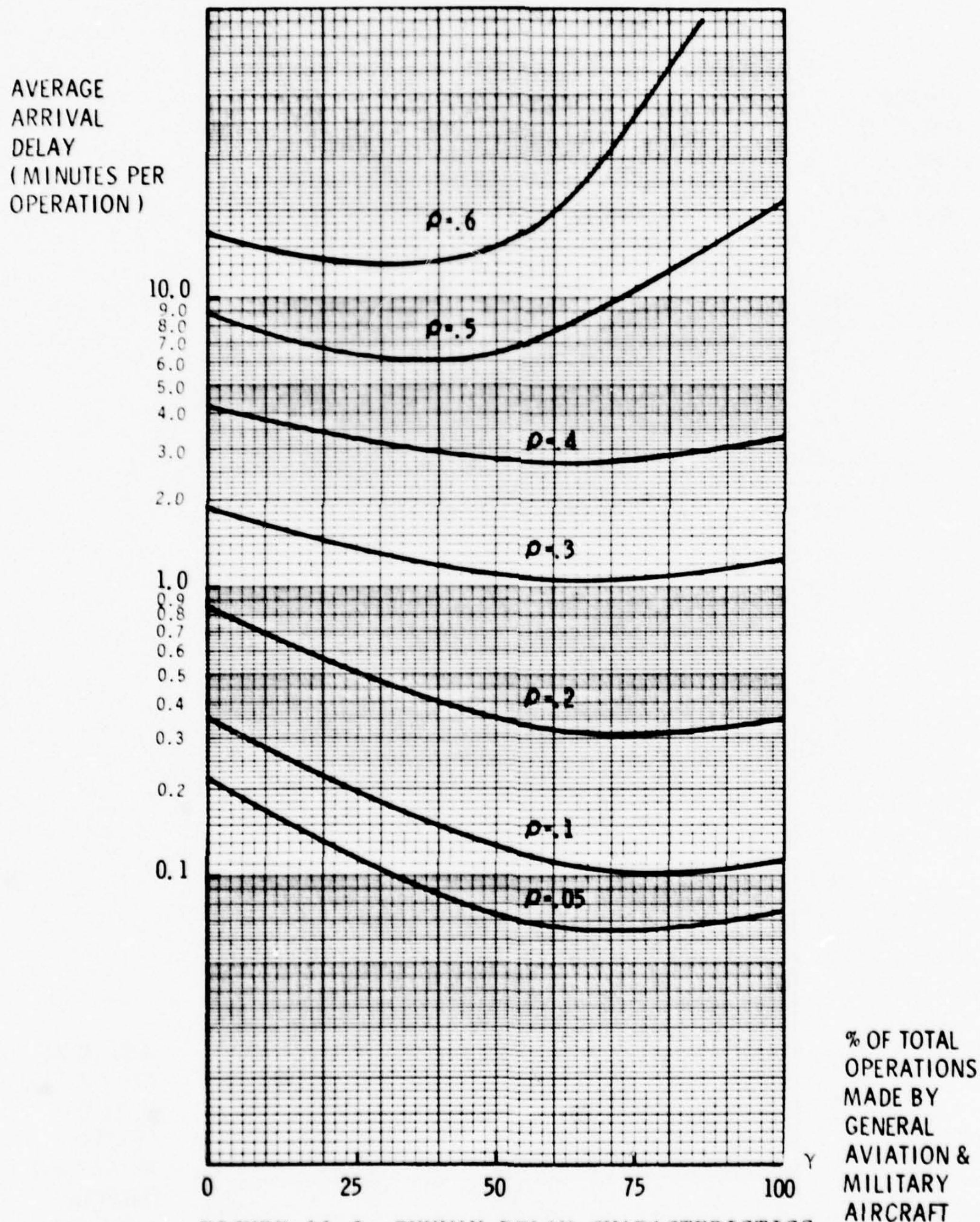

FIGURE 11.2 RUNWAY DELAY CHARACTERISTICS

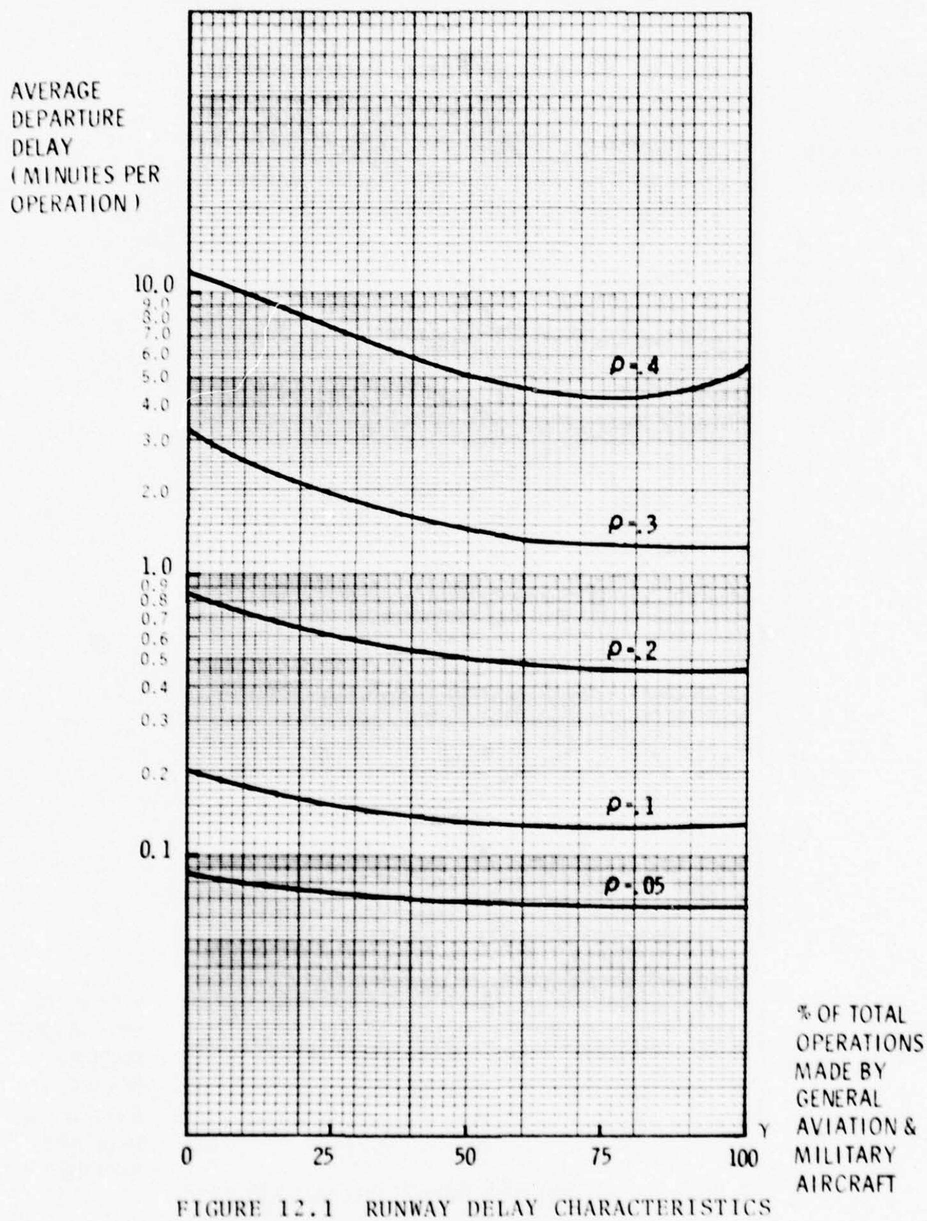

FIGURE 12.1 RUNWAY DELAY CHARACTERISTICS

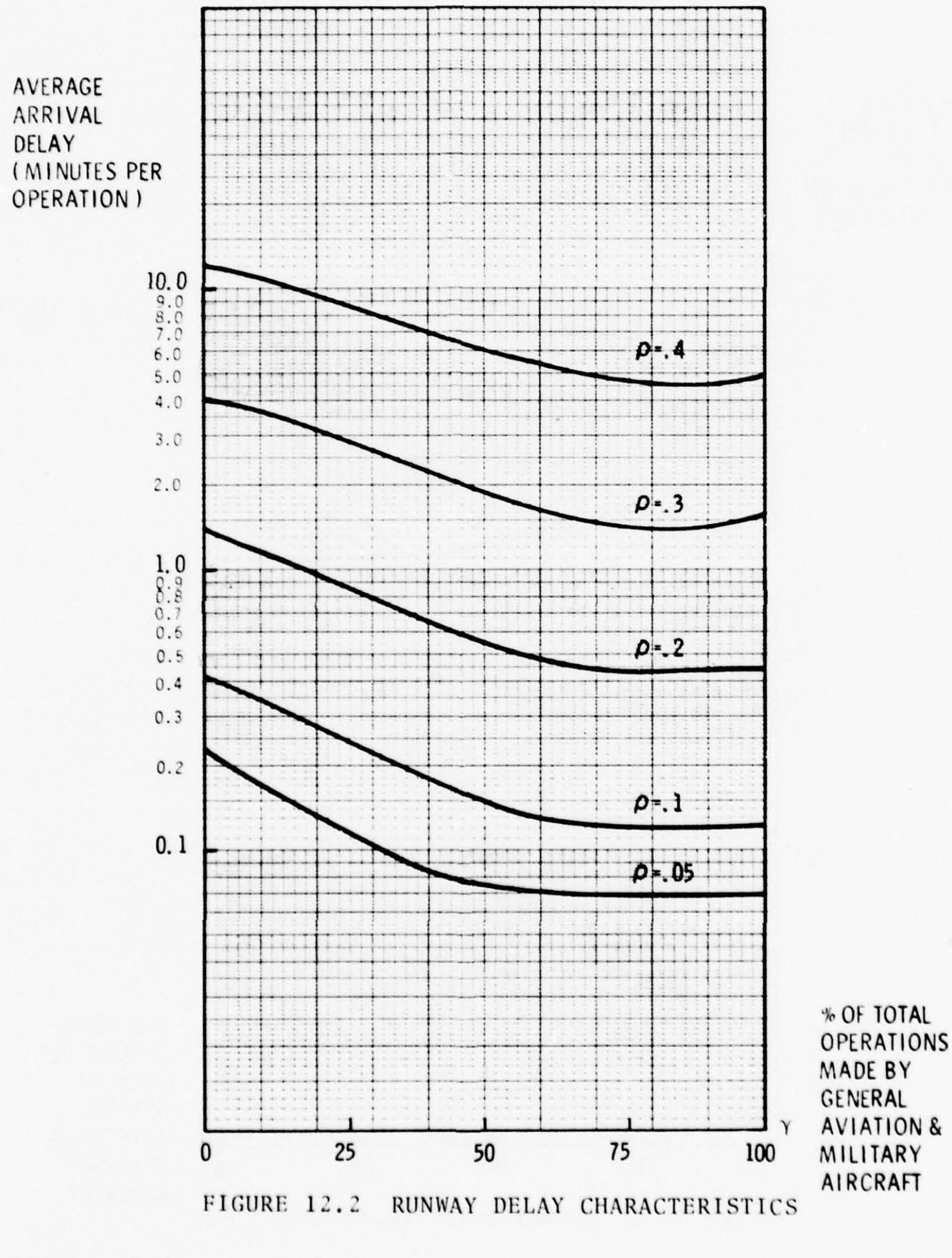

FIGURE 12.2 RUNWAY DELAY CHARACTERISTICS

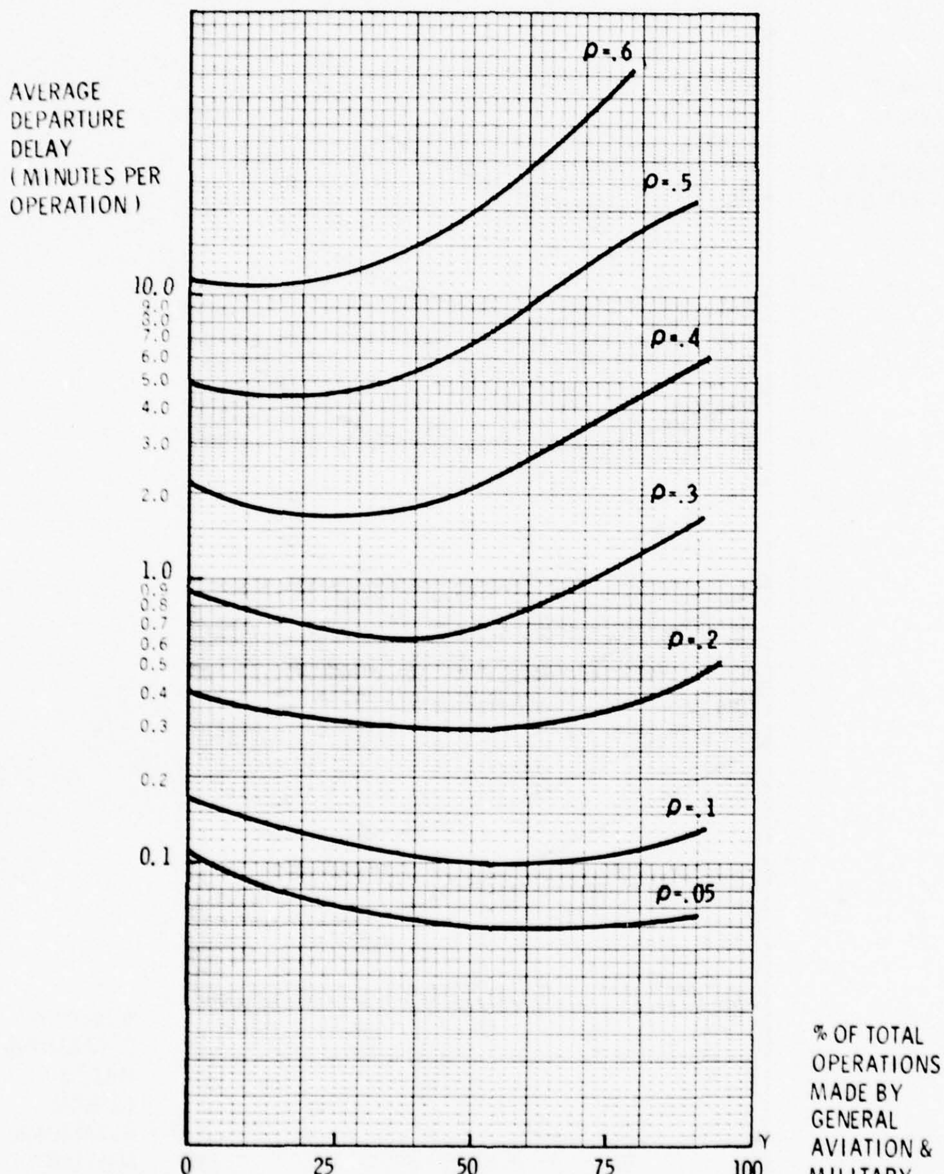

FIGURE 13.1 RUNWAY DELAY CHARACTERISTICS

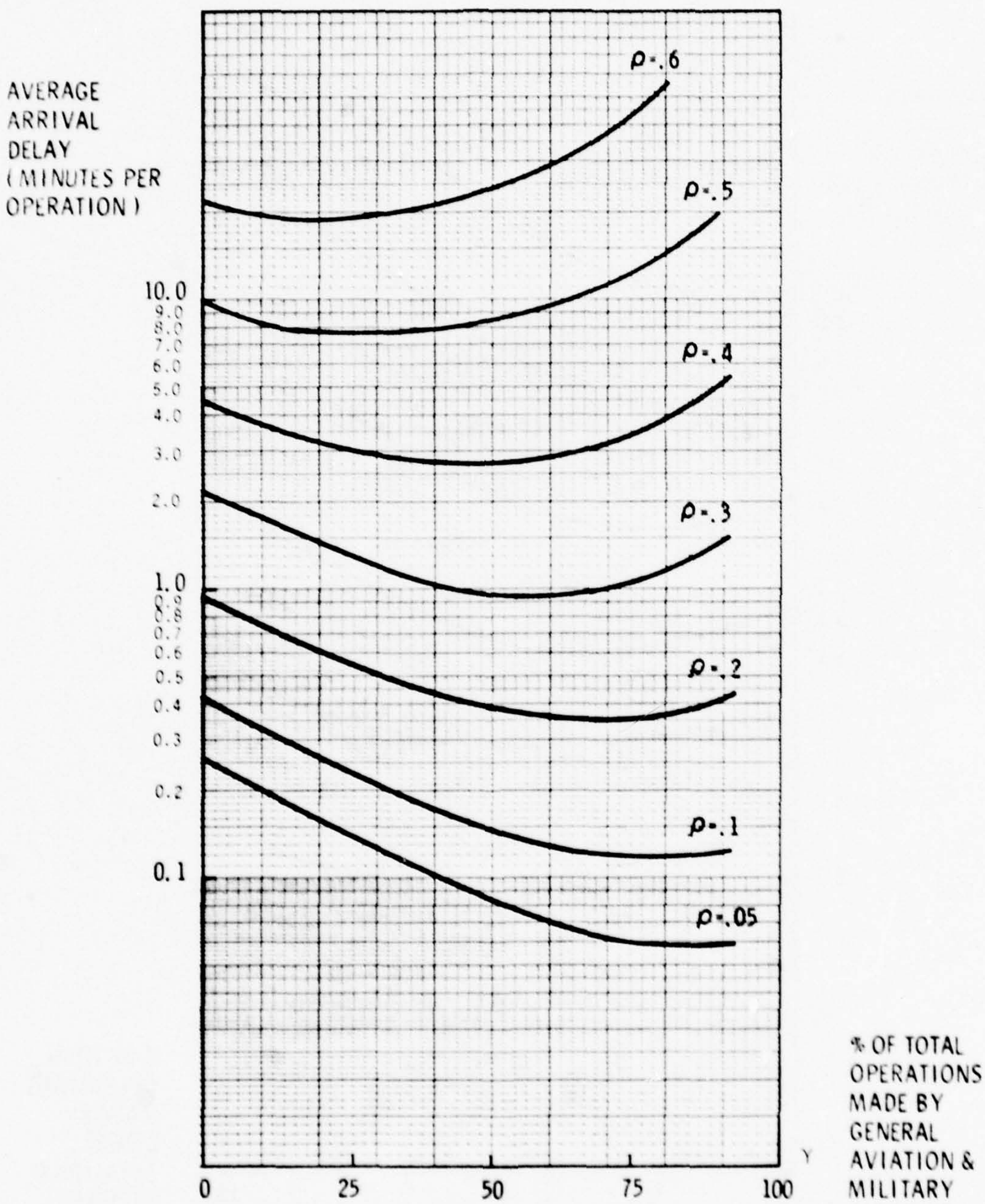

FIGURE 13.2 RUNWAY DELAY CHARACTERISTICS

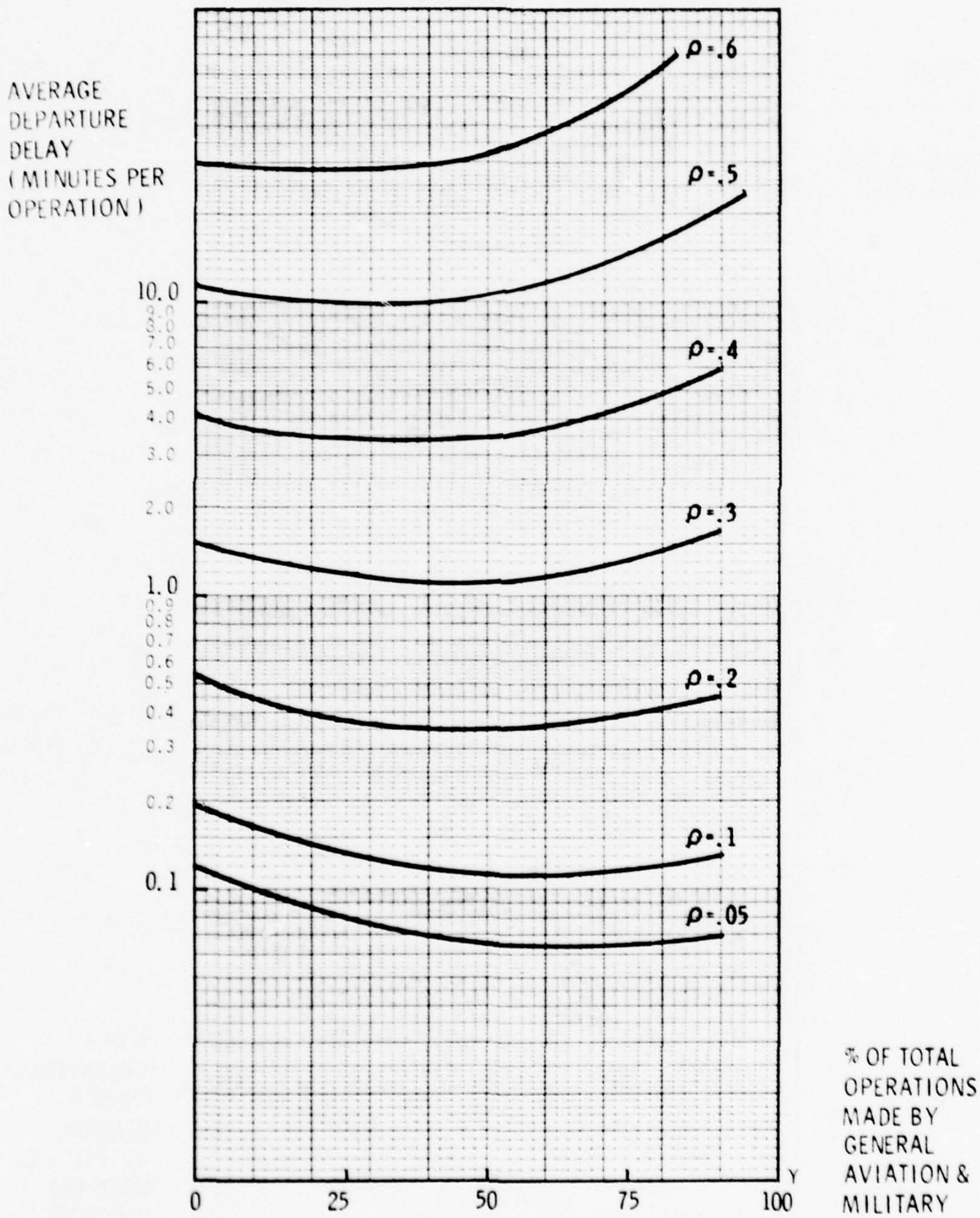

FIGURE 14.1 RUNWAY DELAY CHARACTERISTICS

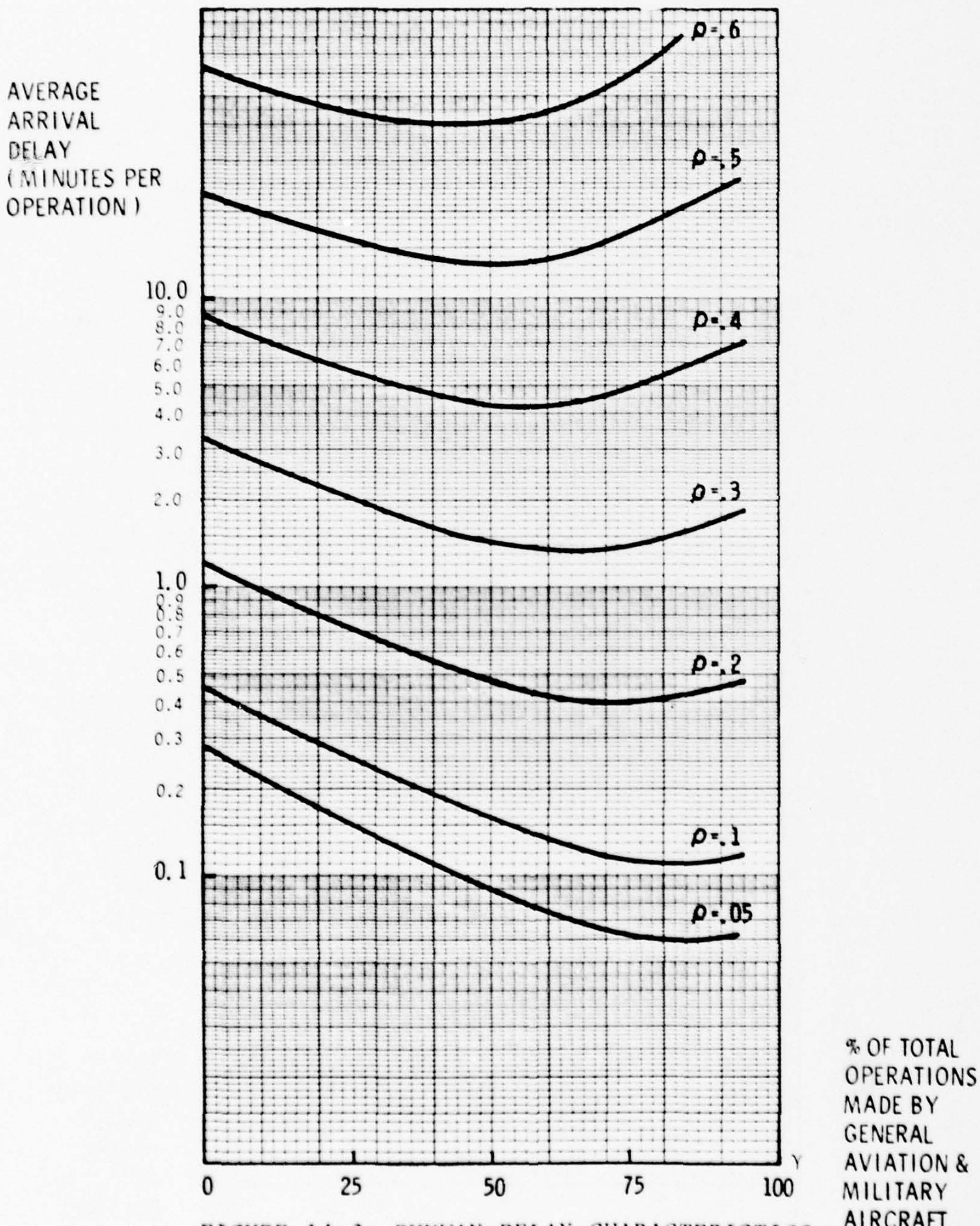

FIGURE 14.2 RUNWAY DELAY CHARACTERISTICS

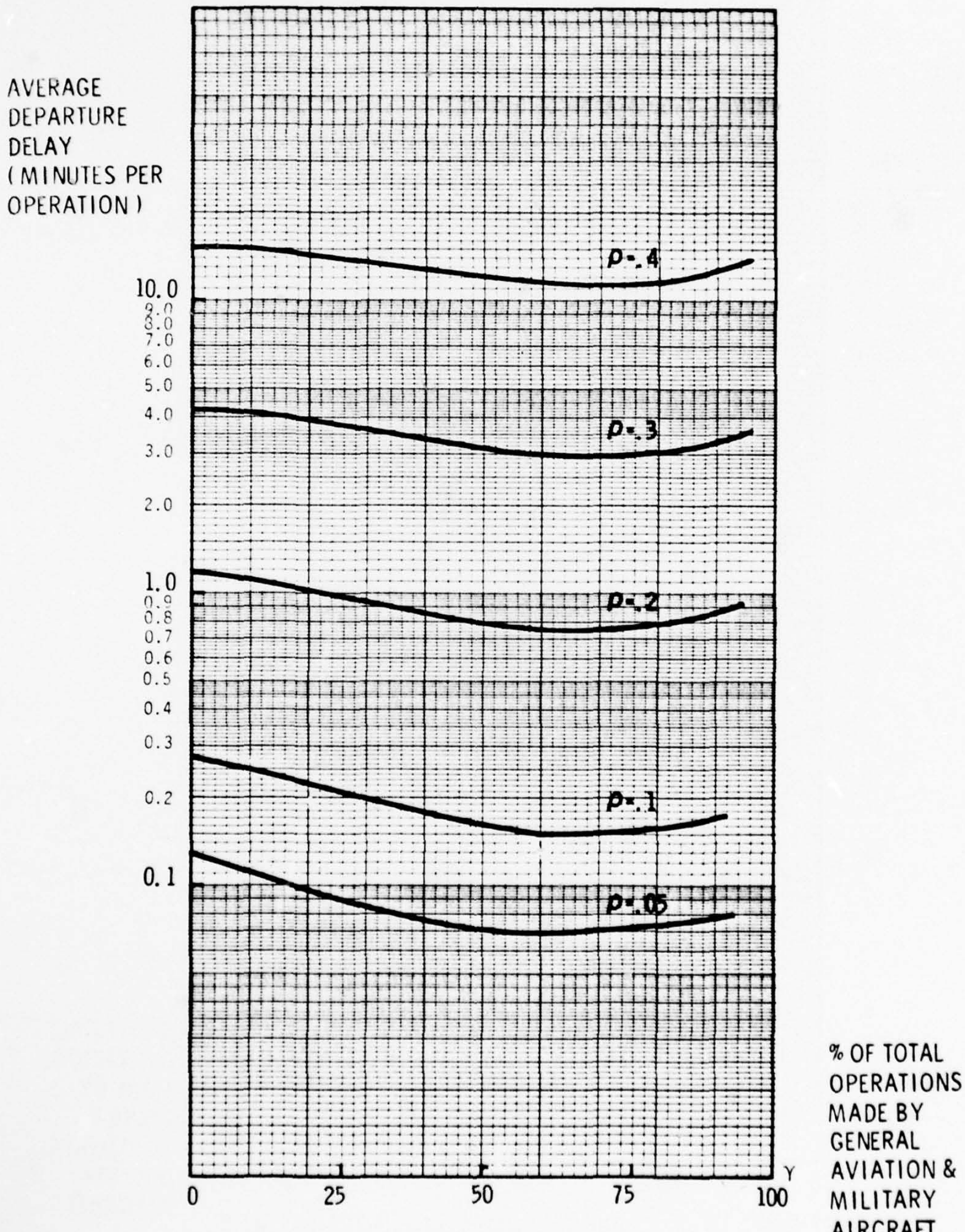

FIGURE 15.1 RUNWAY DELAY CHARACTERISTICS

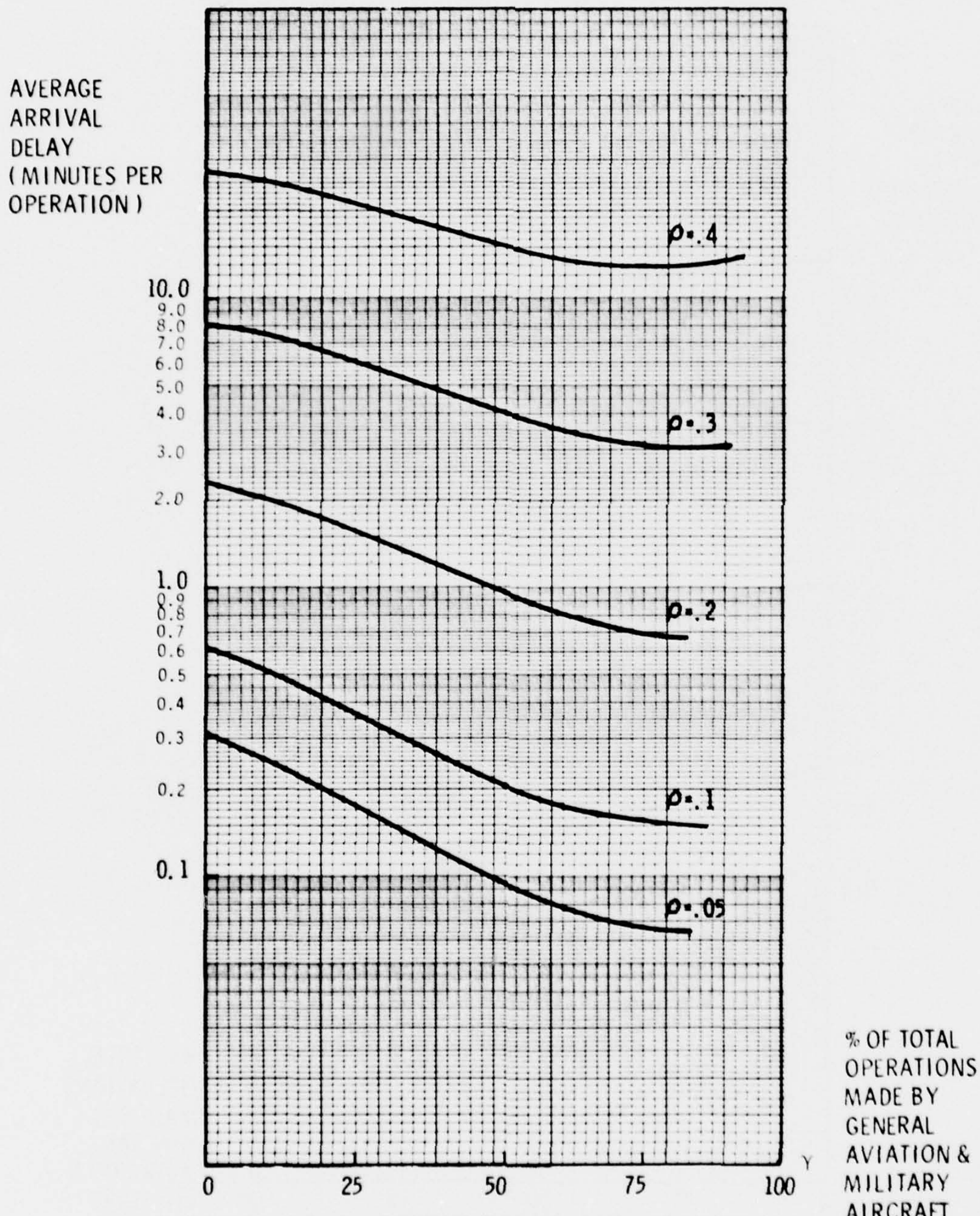

FIGURE 15.2 RUNWAY DELAY CHARACTERISTICS

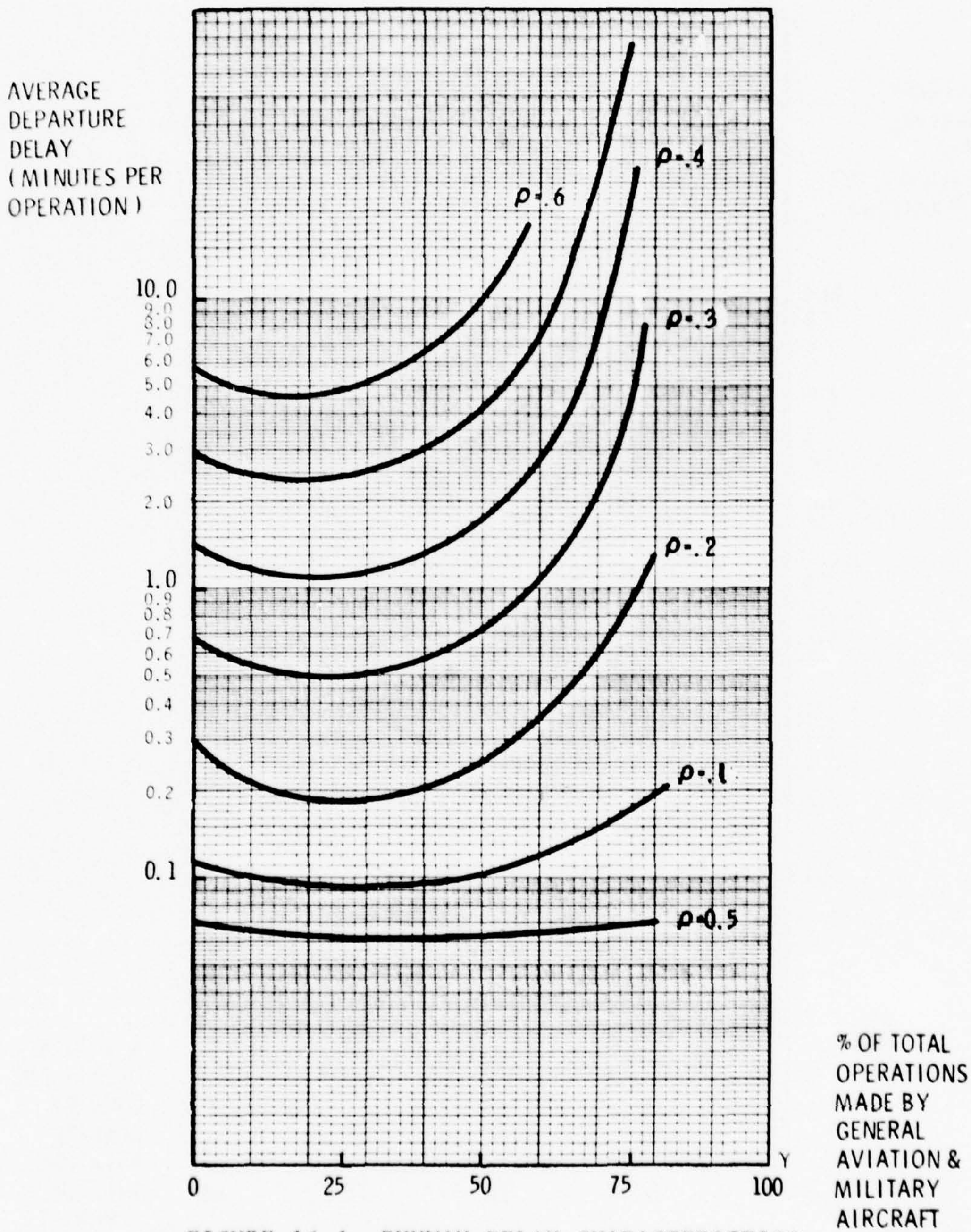

FIGURE 16.1 RUNWAY DELAY CHARACTERISTICS

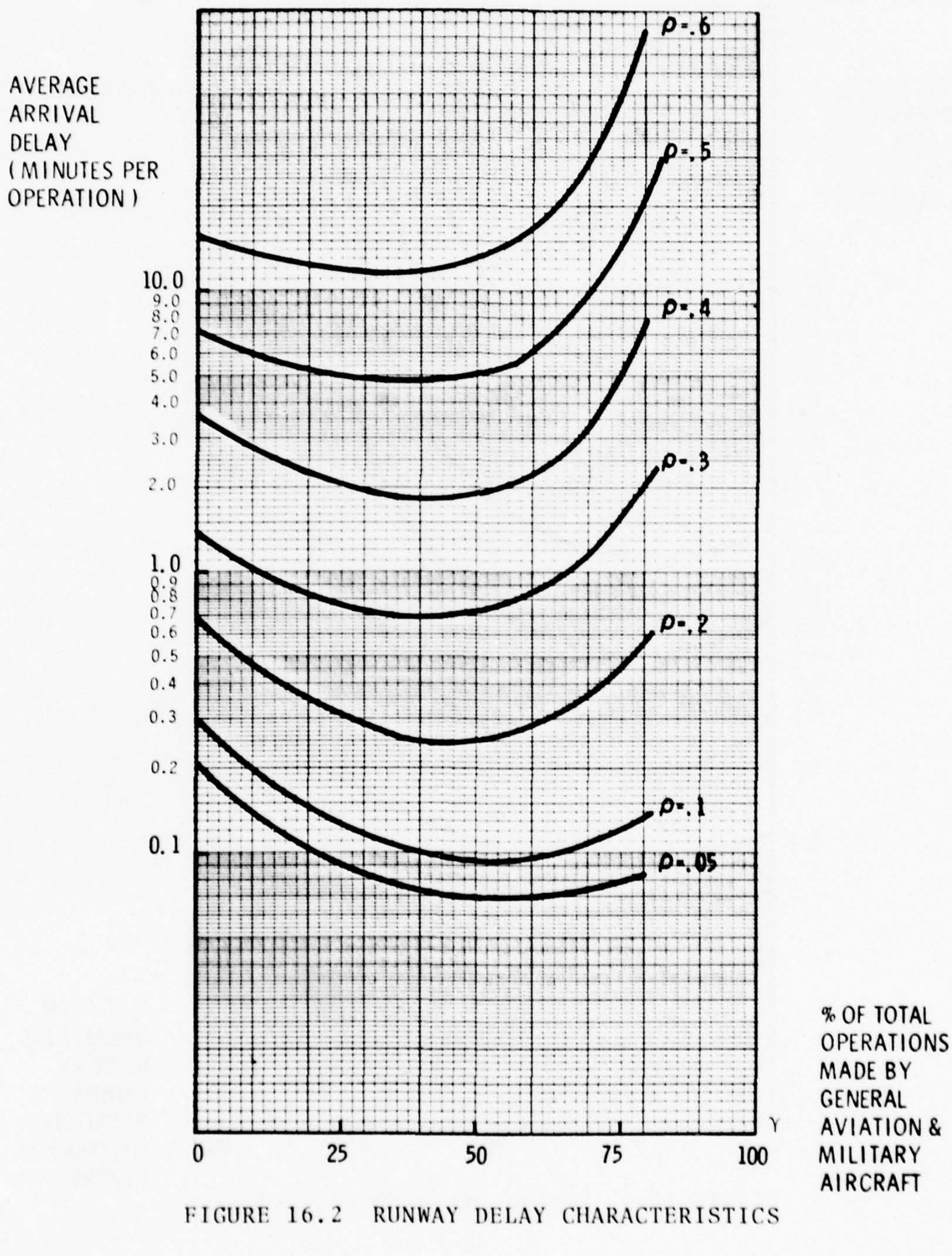

FIGURE 16.2 RUNWAY DELAY CHARACTERISTICS

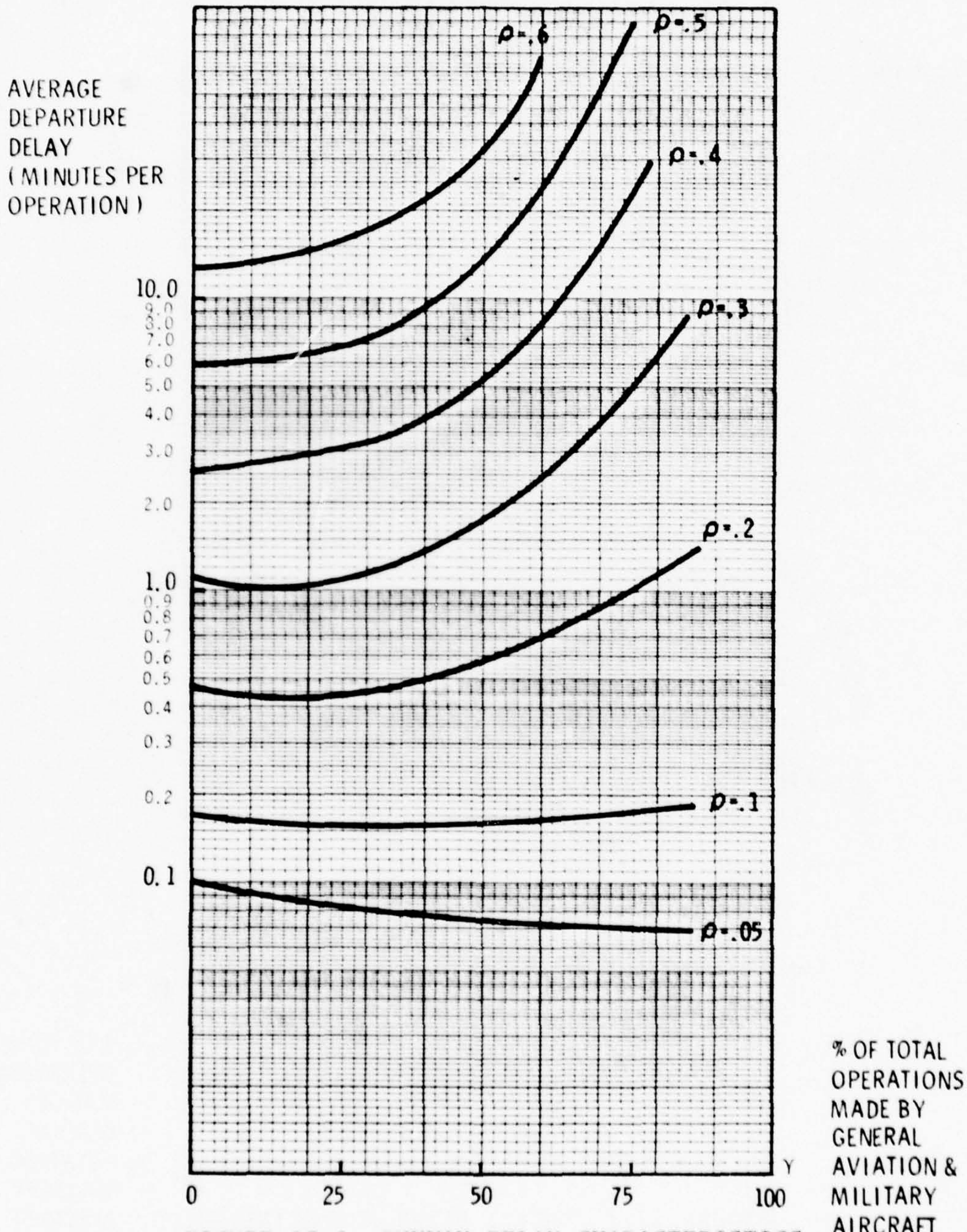

FIGURE 17.1 RUNWAY DELAY CHARACTERISTICS

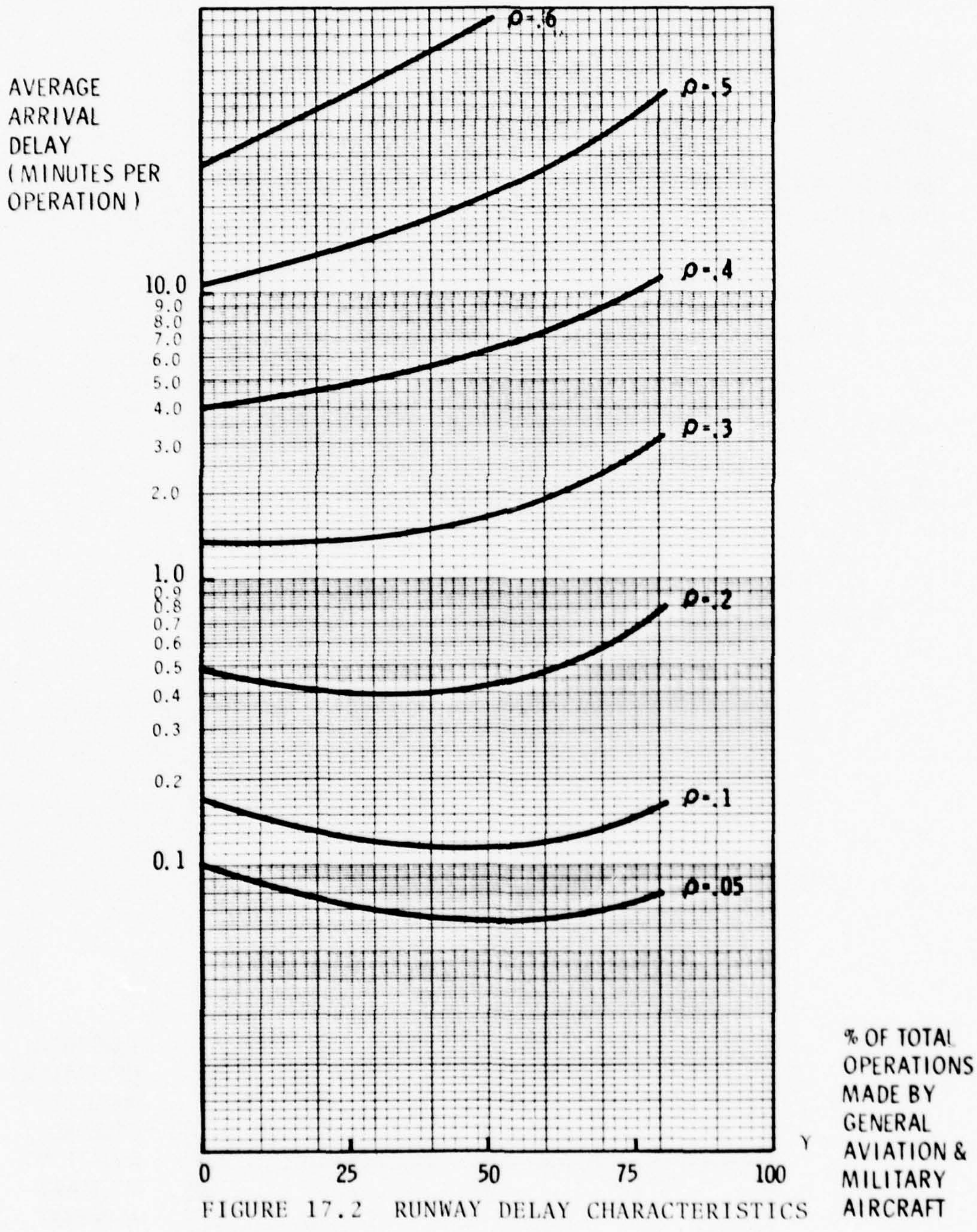

FIGURE 17.2 RUNWAY DELAY CHARACTERISTICS

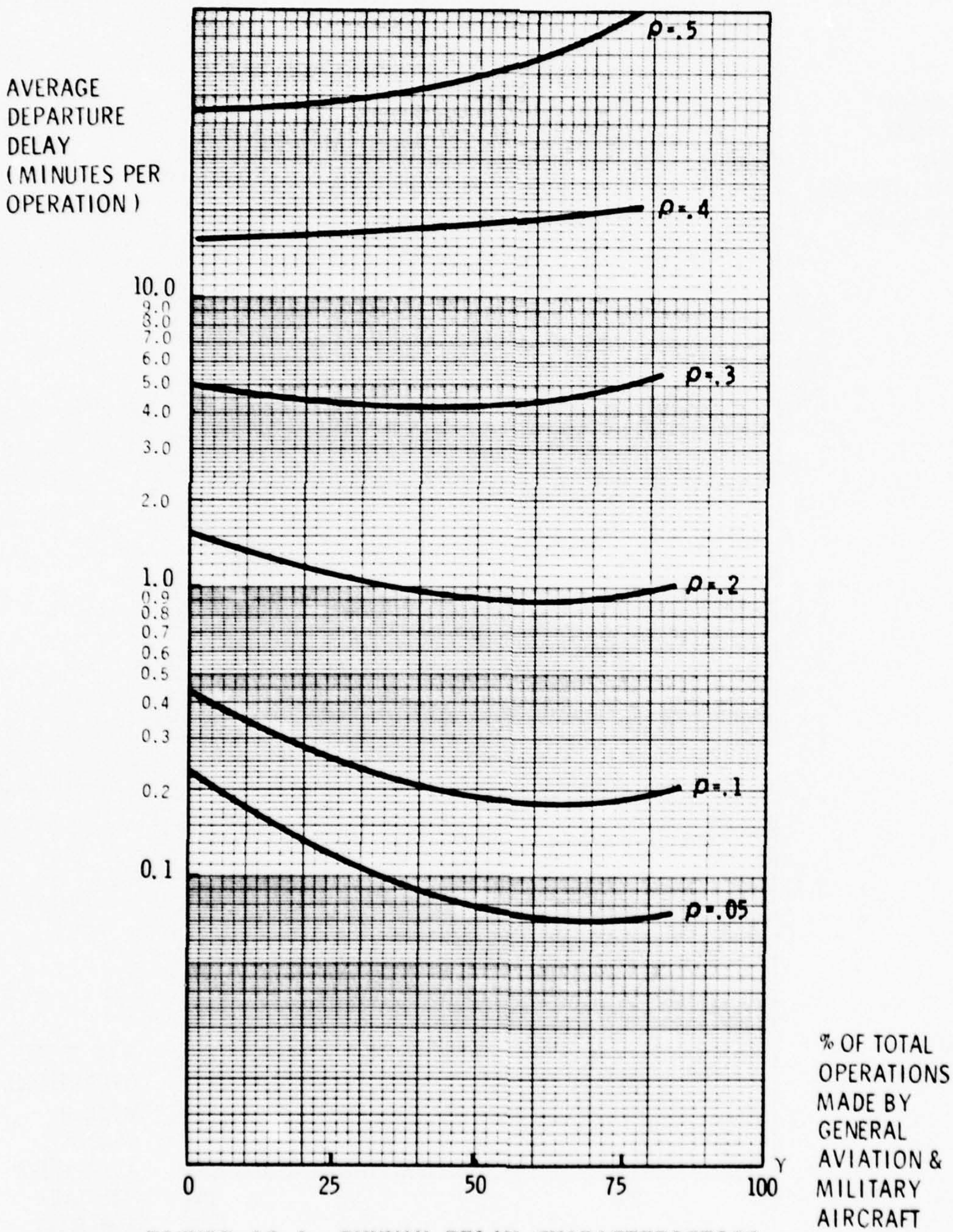

FIGURE 18.1 RUNWAY DELAY CHARACTERISTICS

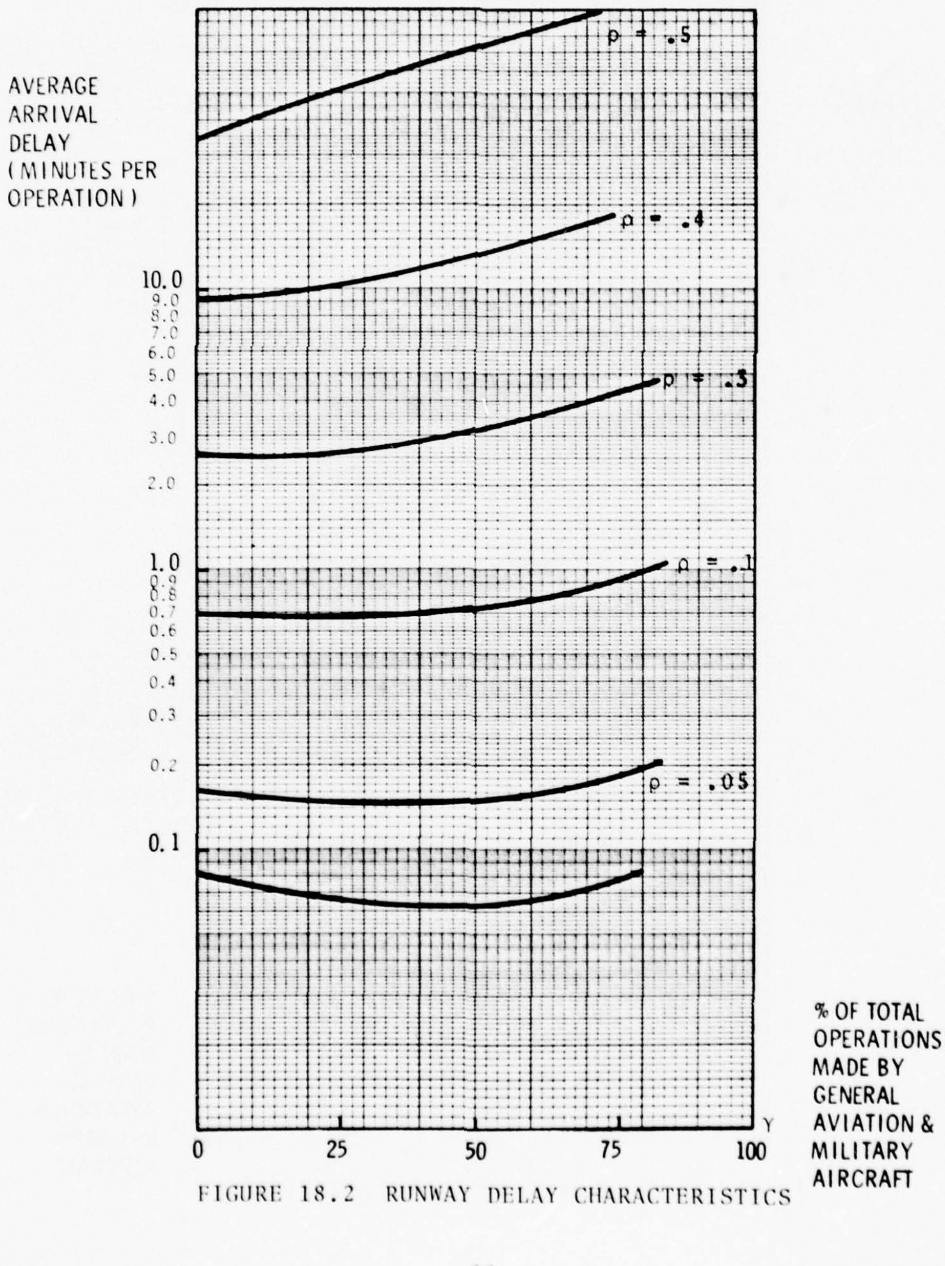

FIGURE 18.2 RUNWAY DELAY CHARACTERISTICS

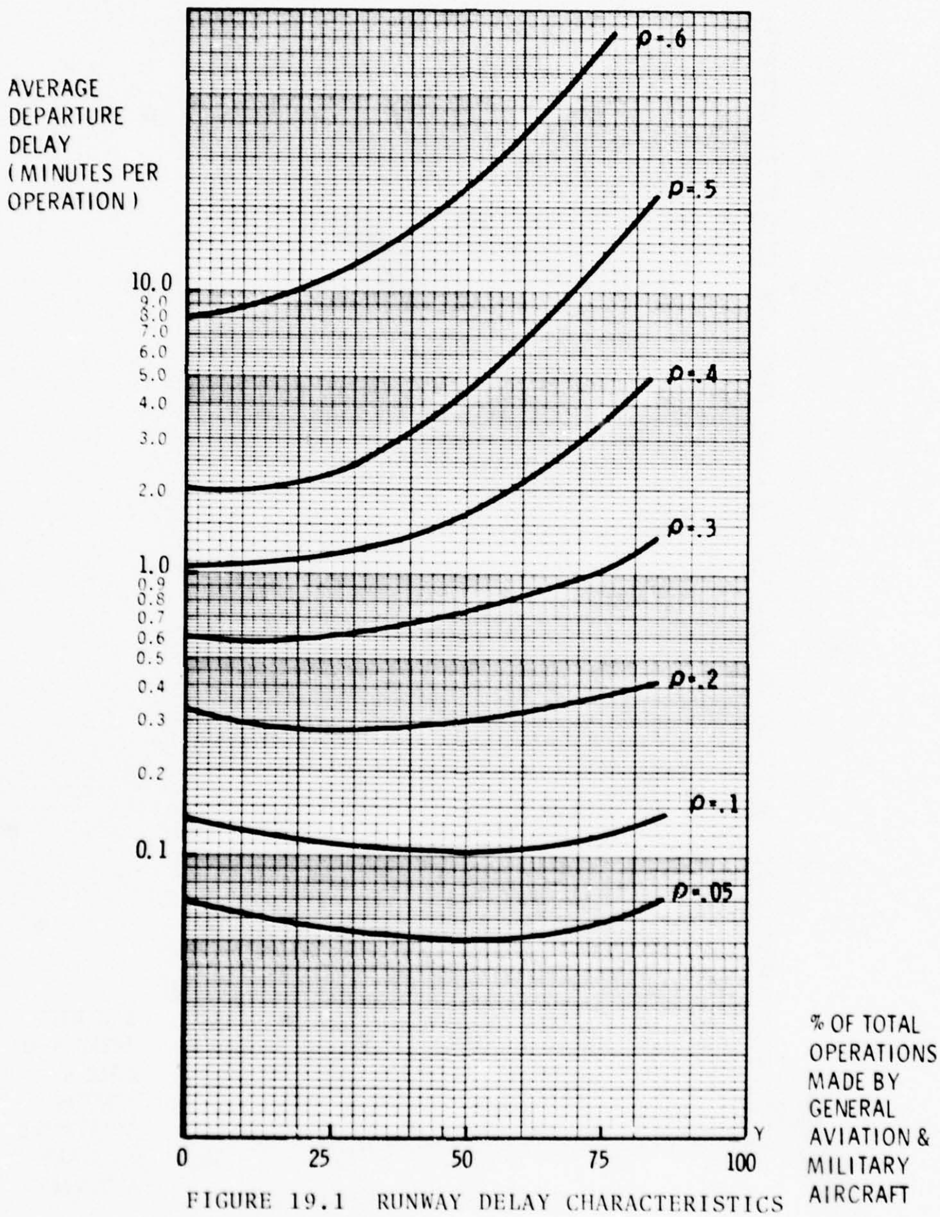

FIGURE 19.1 RUNWAY DELAY CHARACTERISTICS

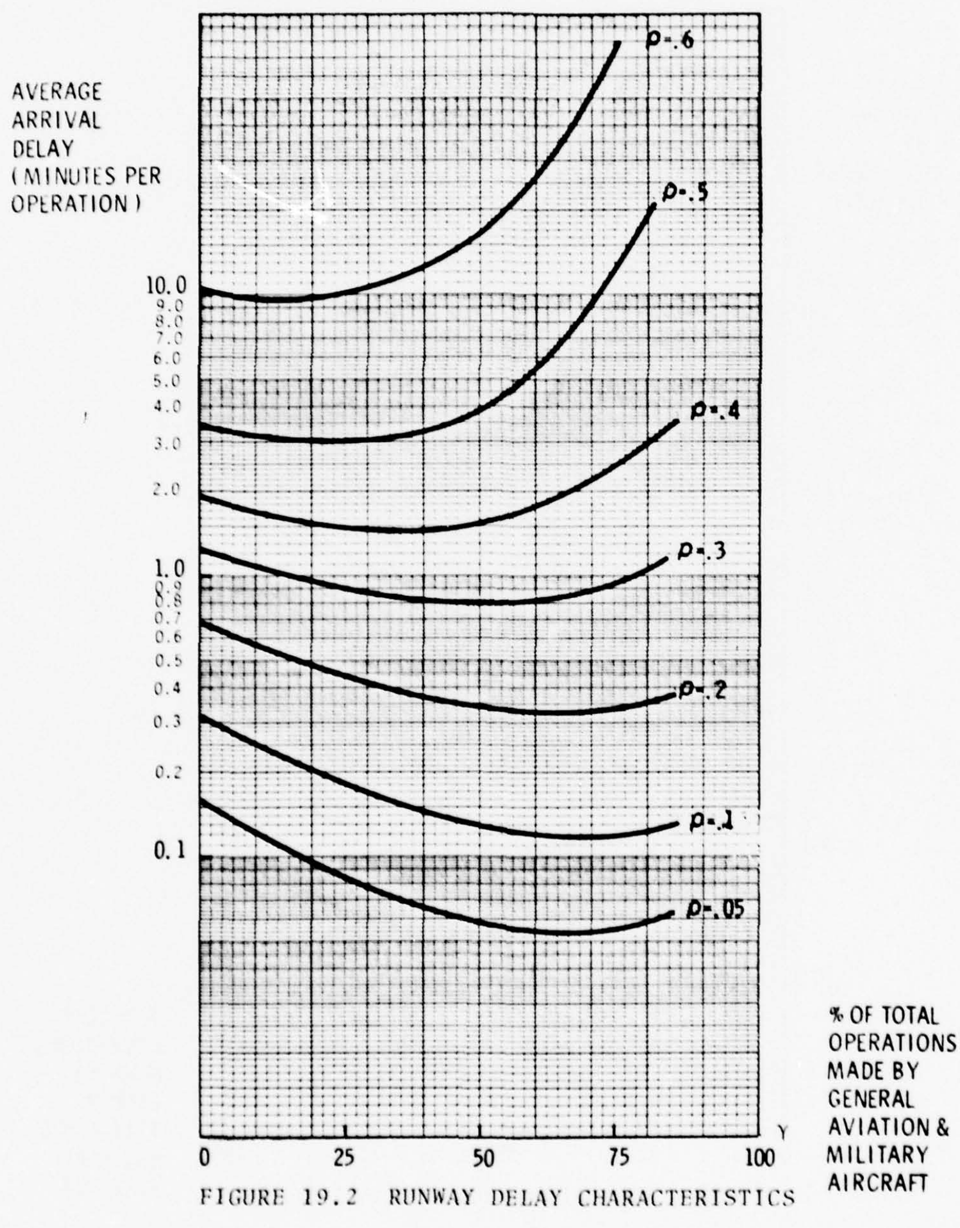

FIGURE 19.2 RUNWAY DELAY CHARACTERISTICS

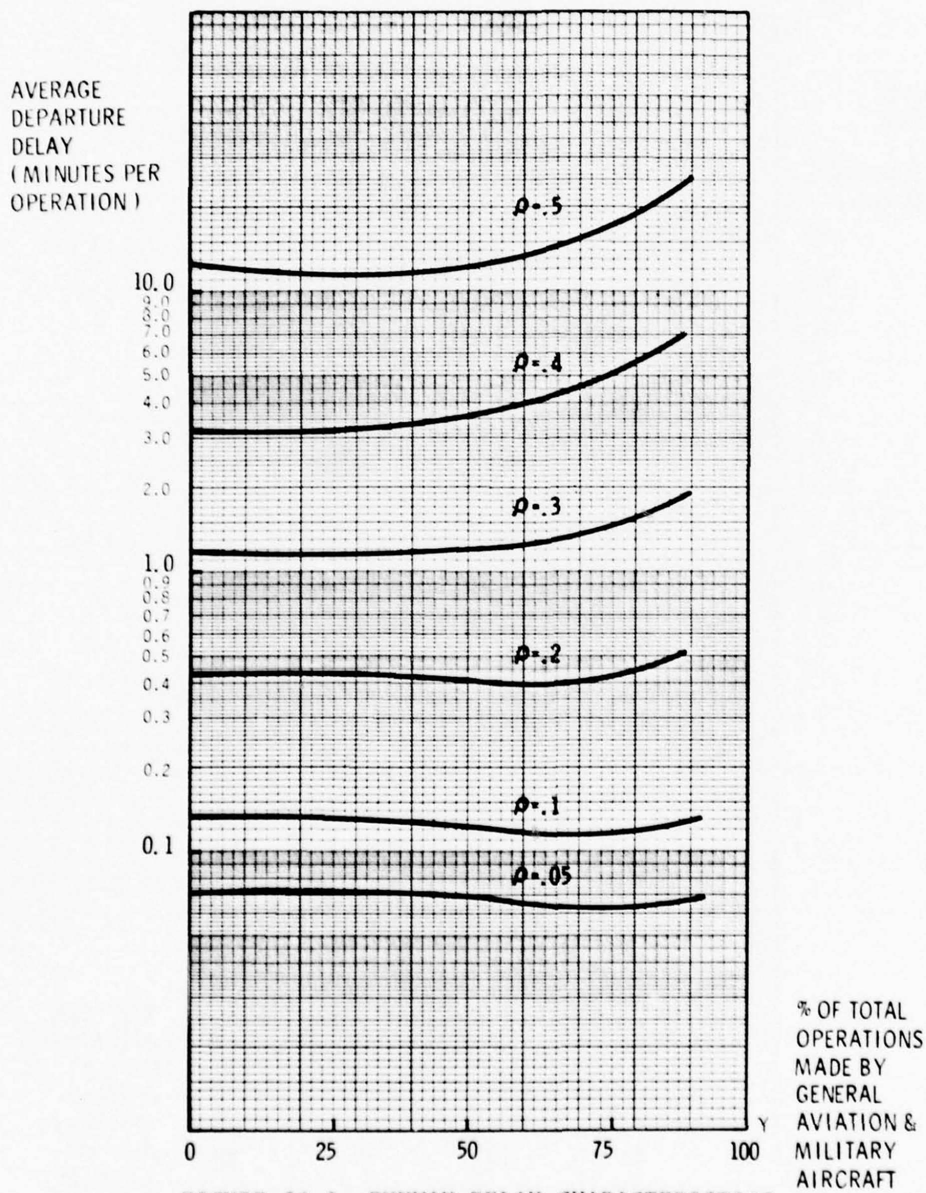

FIGURE 20.1 RUNWAY DELAY CHARACTERISTICS

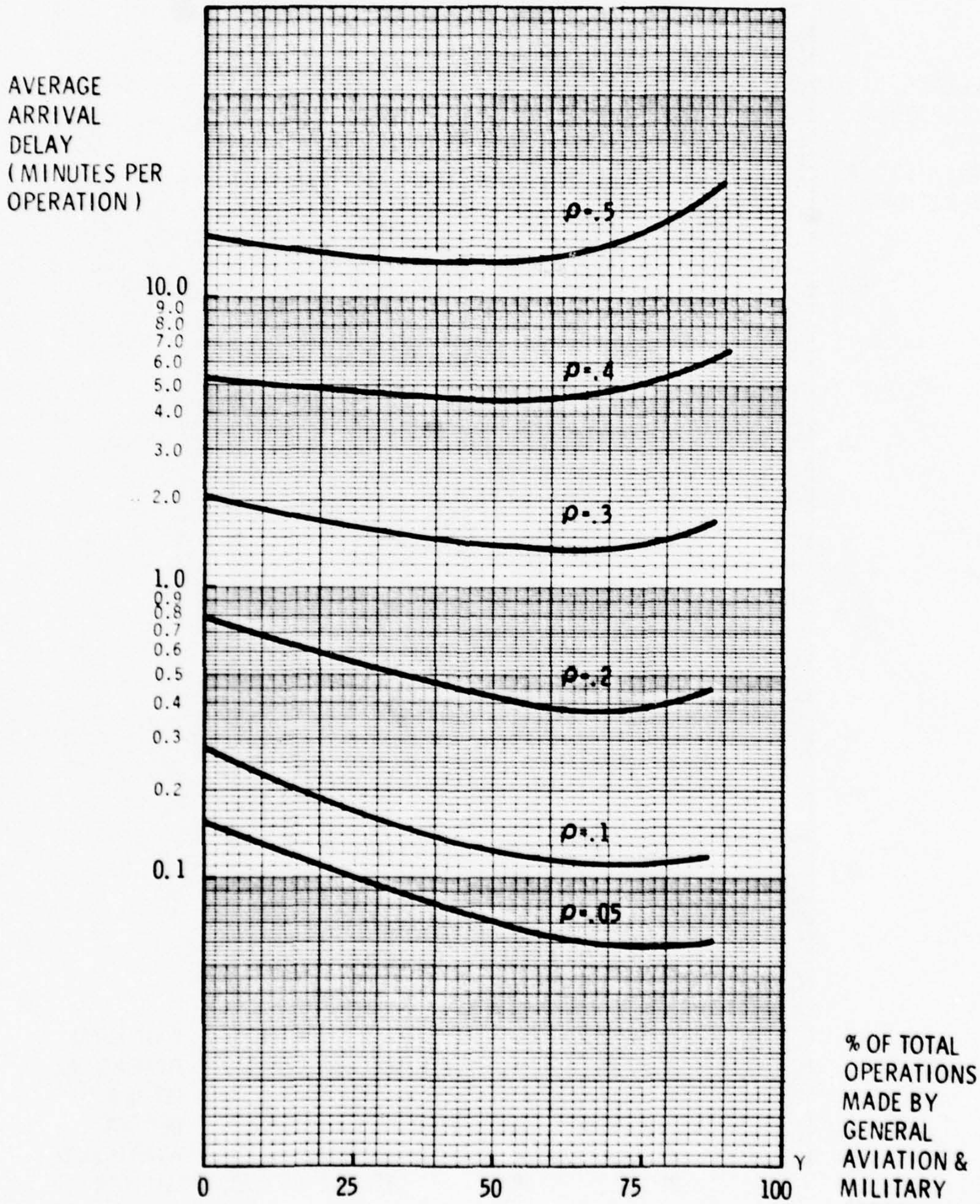

FIGURE 20.2 RUNWAY DELAY CHARACTERISTICS

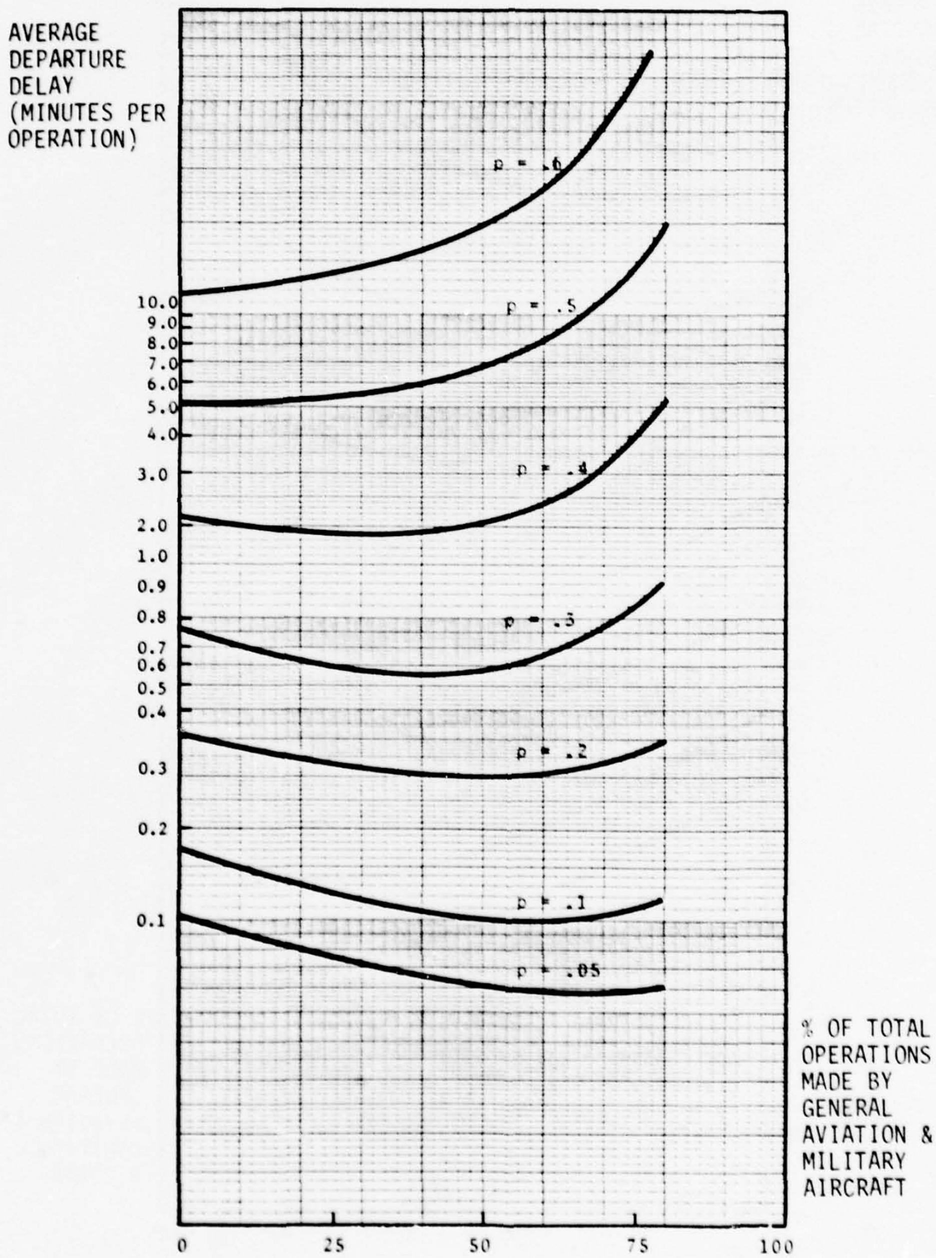

FIGURE 21.1 RUNWAY DELAY CHARACTERISTICS

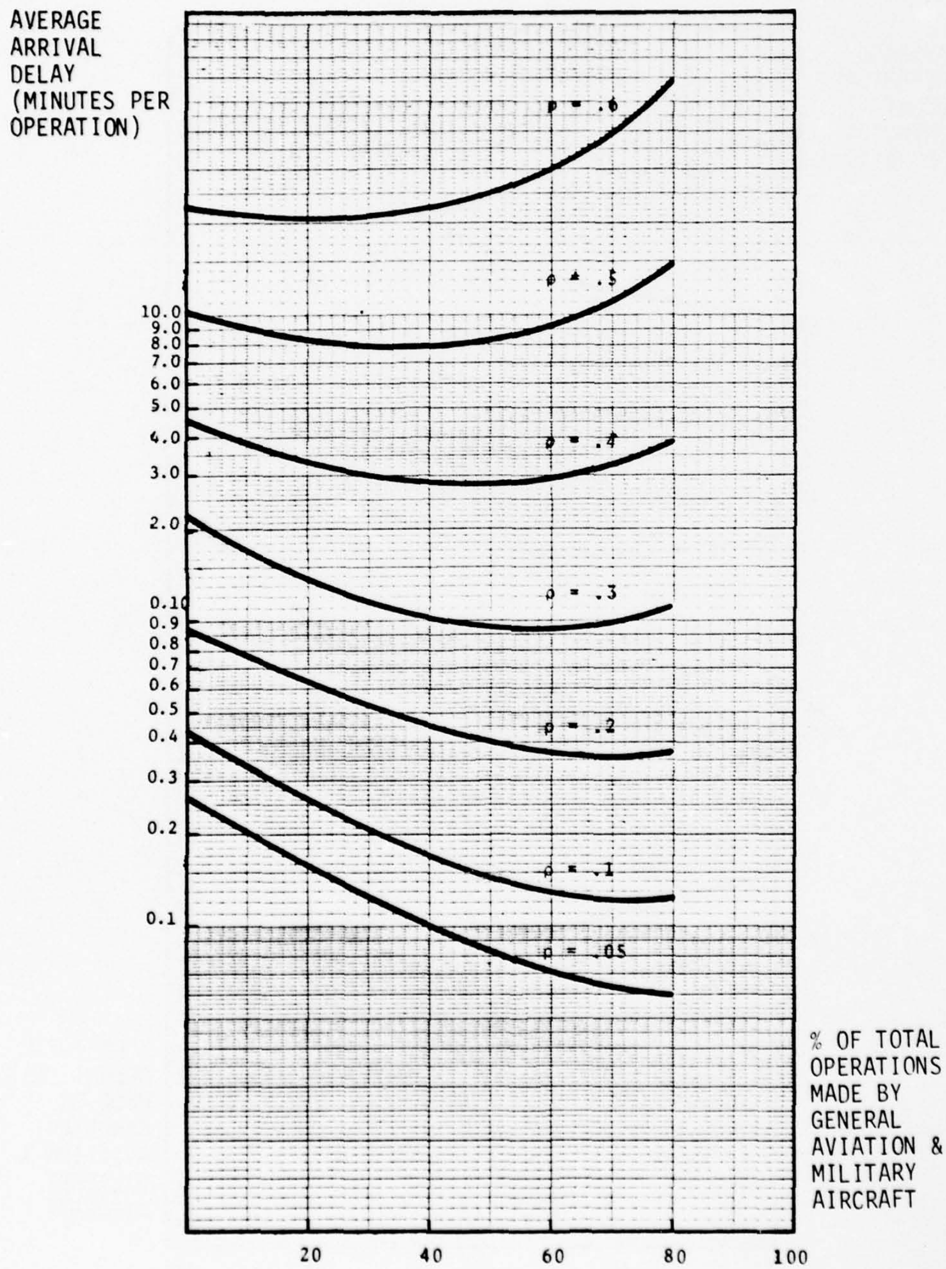

FIGURE 21.2 RUNWAY DELAY CHARACTERISTICS

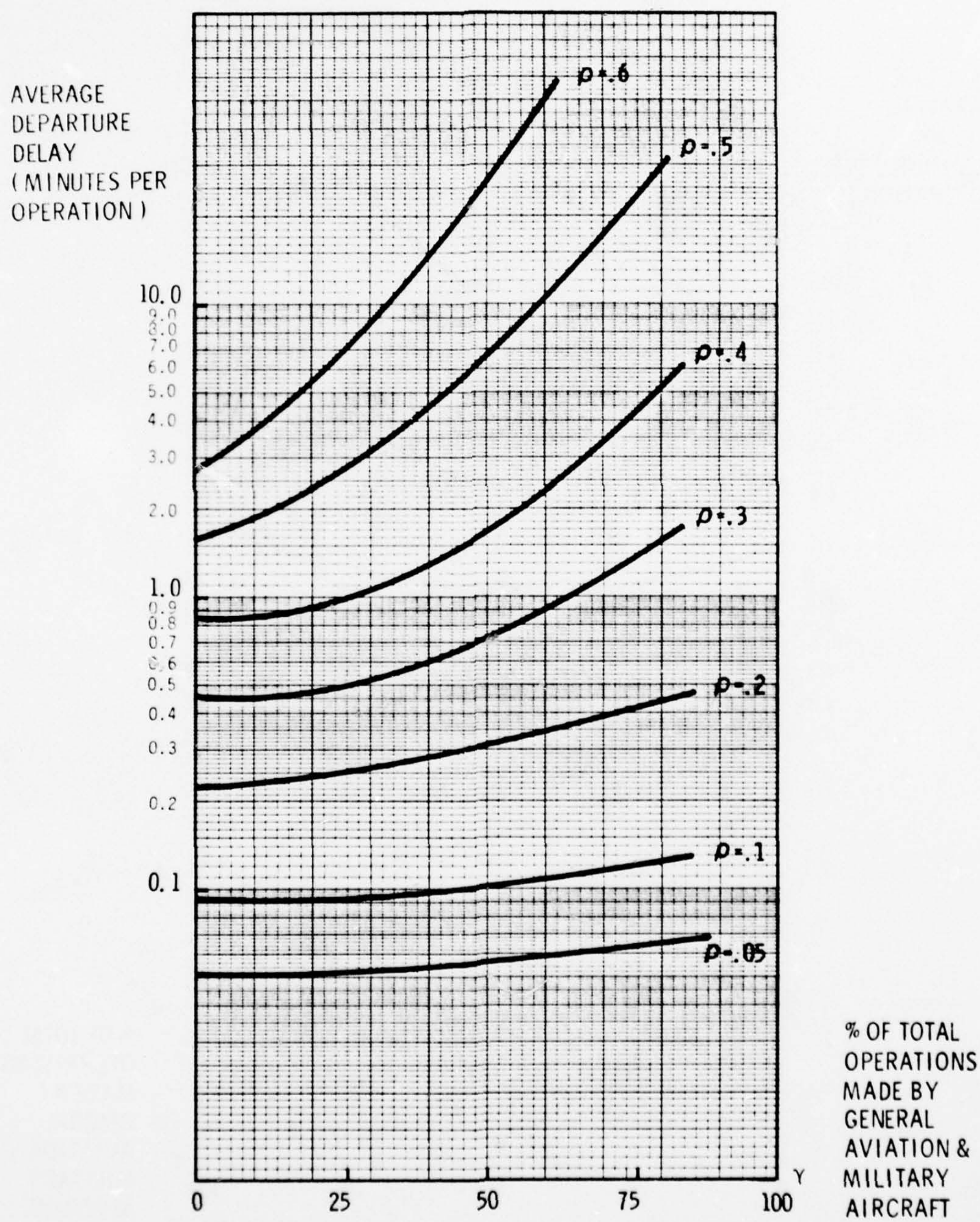

FIGURE 22.1 RUNWAY DELAY CHARACTERISTICS

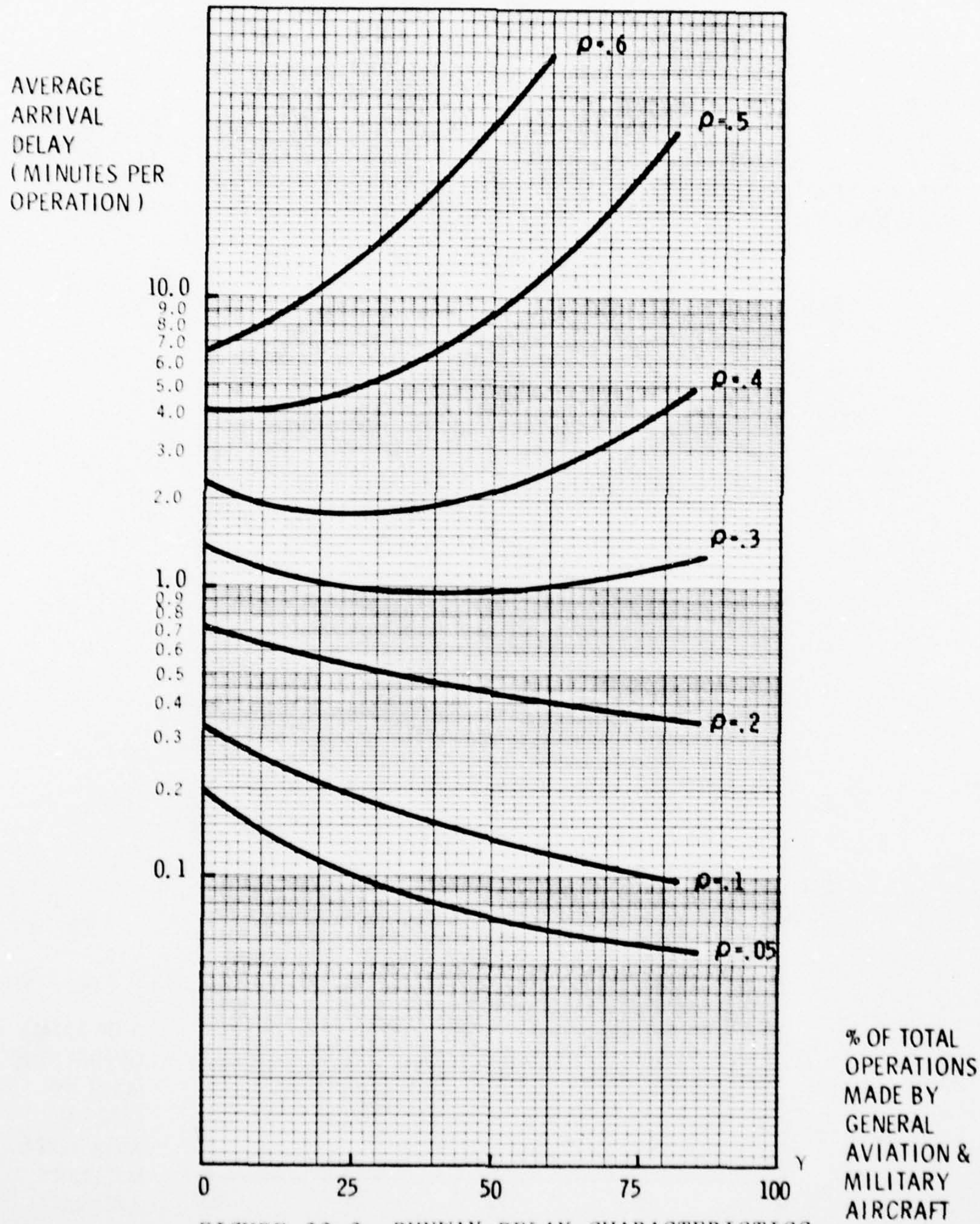

FIGURE 22.2 RUNWAY DELAY CHARACTERISTICS

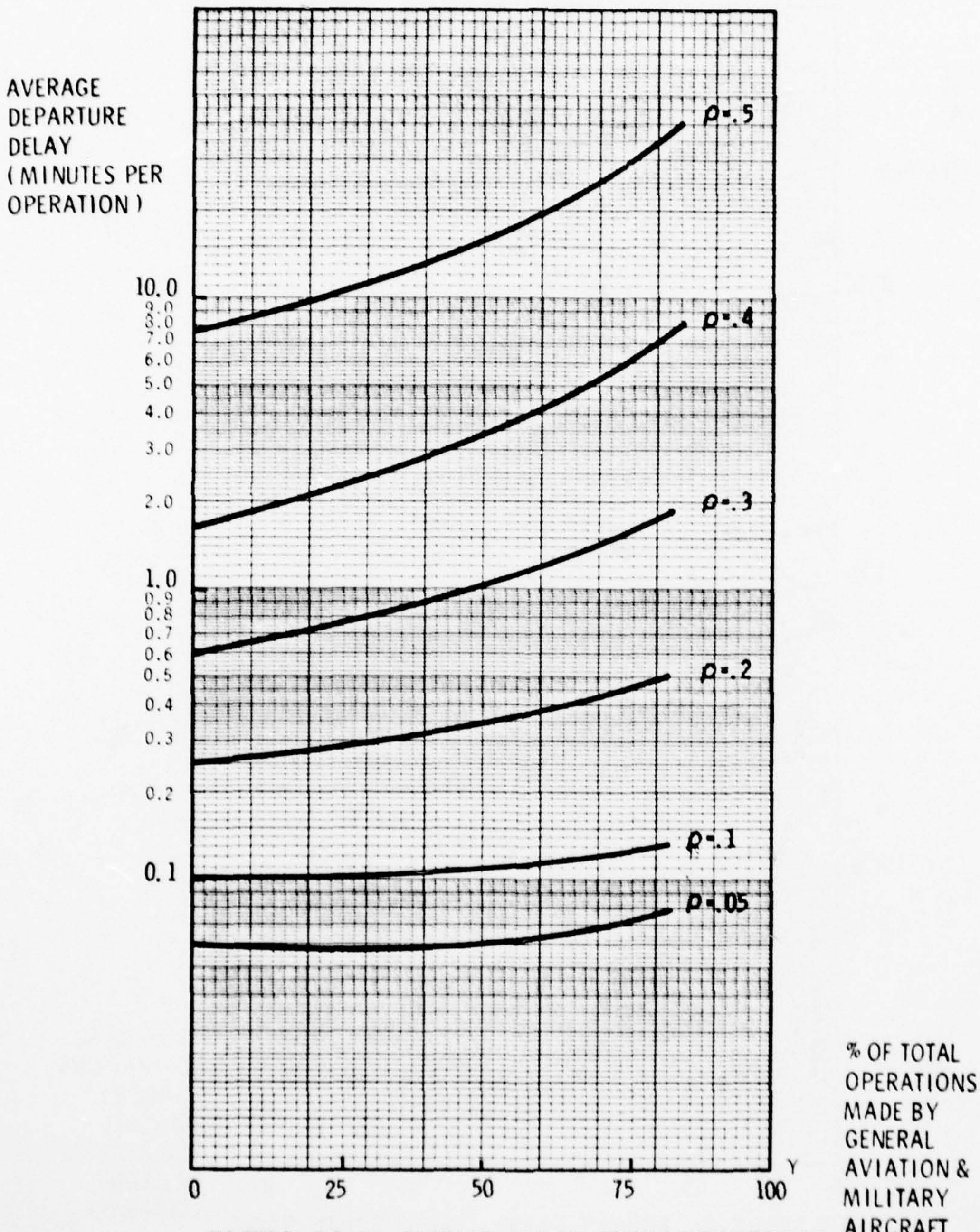

FIGURE 23.1 RUNWAY DELAY CHARACTERISTICS

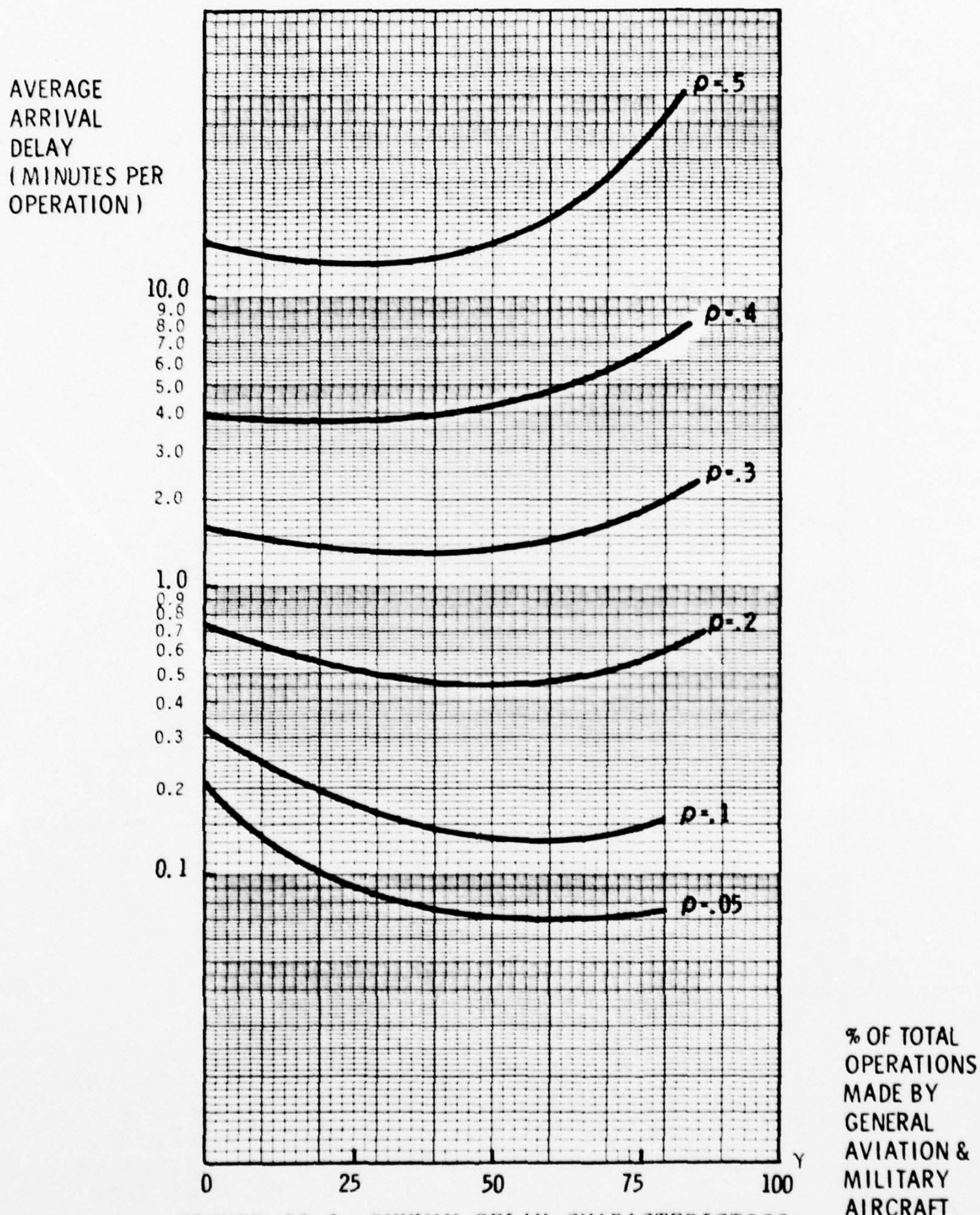

FIGURE 23.2 RUNWAY DELAY CHARACTERISTICS

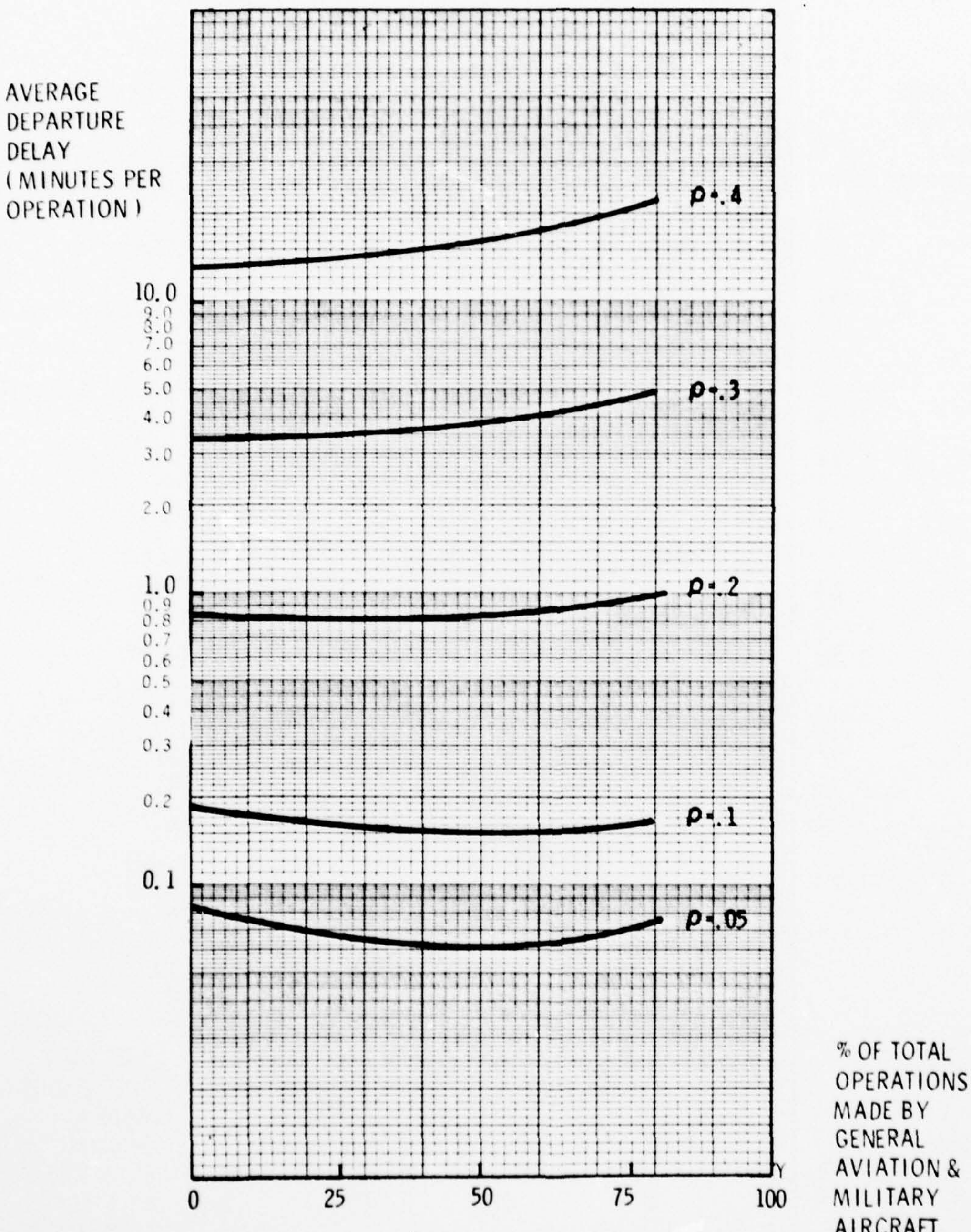

FIGURE 24.1 RUNWAY DELAY CHARACTERISTICS

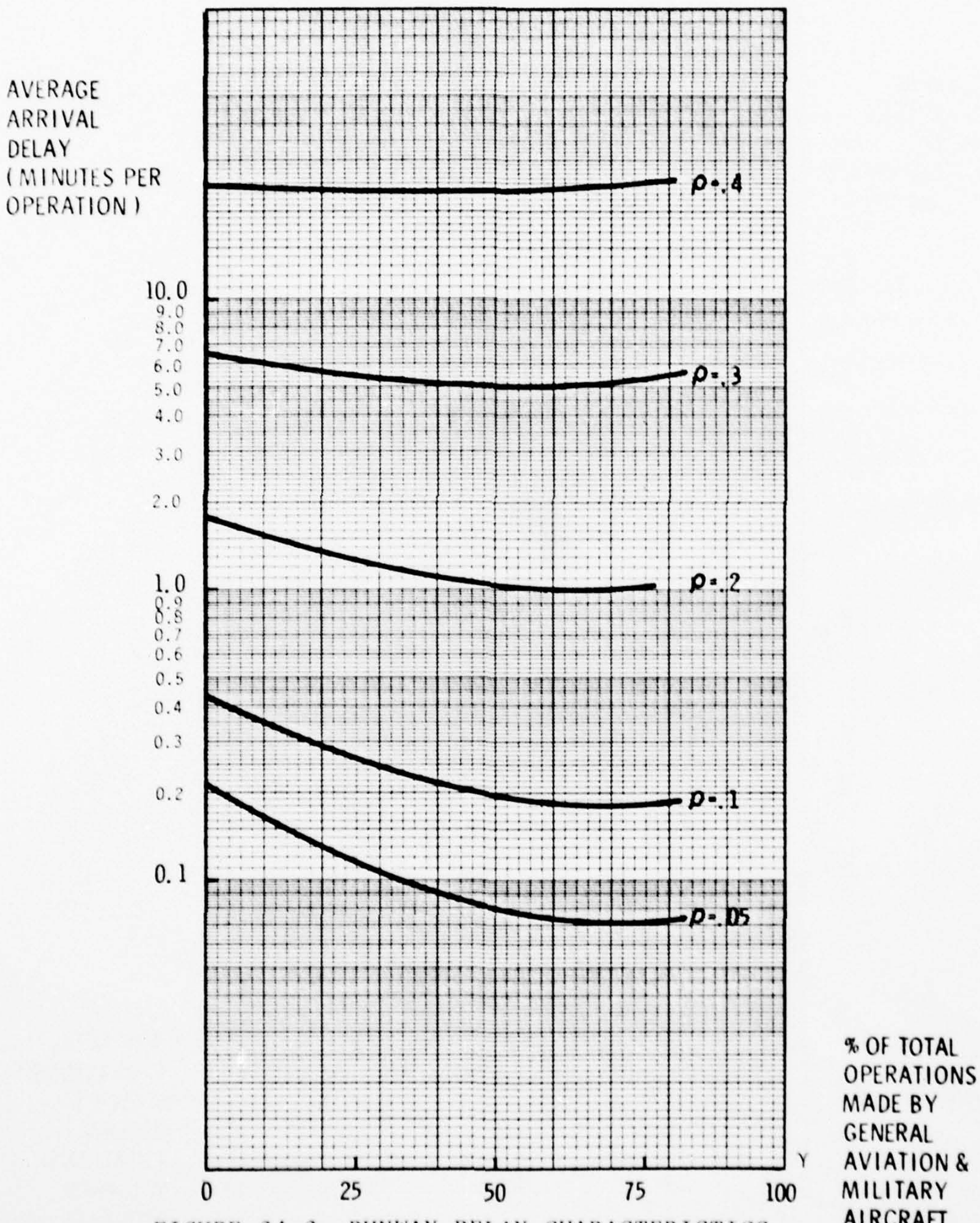

FIGURE 24.2 RUNWAY DELAY CHARACTERISTICS

4. ESTIMATE THE VALUE OF AIRPORT DELAY REDUCTION

A reduction in airport runway delays produces two types of economic benefits to be treated here -- more efficient aircraft operation, and reduced passenger time lost to delays. The magnitudes of both types of benefits are related to the changes in runway delays experienced at an airport, but airport specific fleet mix and aircraft load factors also influence their final value.

4.1 AIRCRAFT OPERATING COST REDUCTION

Aircraft operating cost reductions are based on the type of aircraft serving the airport and on the amount of delay time saved for aircraft arrivals and departures. The aircraft operating cost savings, S, are given by the relationship

$$S - K \cdot L + C \cdot T$$

where K and C are the average aircraft operating costs on landing and on takeoff, Table 10, and L and T are the delay reductions for landing and for takeoff calculated in Section 3. K is greater than C because aircraft fuel consumption is greater during landing and approach than during idling prior to takeoff. The sizes of K and C for a particular airport depend on the airport fleet mix. Table 10 shows aircraft hourly operating costs for the seven classes of aircraft considered in this handbook. A good estimate of K and C can be obtained by averaging the operating costs for all the aircraft serving an airport, using airport fleet mix data from Section 1, Worksheet #1 to weight the costs for individual aircraft types shown in the Table. This process is carried out on Worksheet #5.

4.2 PASSENGER DELAY REDUCTION BENEFITS

Savings in passenger time due to reductions in takeoff and landing delays depend on the number of passengers on board the aircraft as well as on the size of the delay reductions. It is assumed that all aircraft sizes share equally in the delay. Therefore the annual aircraft delay, developed in Section 2, must be multiplied by the average number of passengers on board during an operation. The process is carried out on page 2 of Worksheet #5,

TABLE 10. AIRCRAFT OPERATING COSTS AND SEATING CAPACITIES [1]

AIRCRAFT CATEGORY	OPERATING COSTS[2], DOLLARS/HOUR LANDING COST, K	TAKEOFF COST, C	SEATING CAPACITY
4 Engine Wide Body Jet	2055	1171	352
2, 3, Engine Wide Body Jet	1427	839	236
4 Engine Standard Body Jet	1078	712	144
3 Engine Standard Body Jet	811	573	122
2 Engine Standard Body Jet	646	472	89
Large Turboprop, Piston	385	351	46
Small (<12,500 lb)	23	19	8

[1] Analysis of data found in Aircraft Operating Cost and Performace Report (U.S. Civil Aeronautics Board) Vol. X, July 1976.

[2] Costs are expressed in 1976 dollars. Adjustments to a base year, if necessary, will be made in Section 6. Data on Small aircraft taken from Reference (1), Section 3.6.

WORKSHEET # 5: AIRCRAFT AND PASSENGER BENEFITS

AVERAGE HOURLY OPERATING COST ON LANDING, K

			YEAR 1	YEAR 10
$2055 x	[20]	=	(.00)	(.00)
1427 x	[21]	=	(.00)	(.00)
1078 x	[22]	=	(.00)	(.00)
811 x	[23]	=	(21.56)	(16.22)
646 x	[24]	=	(25.84)	(19.38)
385 x	[25]	=	(46.20)	(42.35)
23 x	[26]	=	(18.86)	(19.32)
	K	=	$(112.46)/HR [71]	$(97.27)/HR [72]

AVERAGE HOURLY OPERATING COST ON TAKEOFF, C

			YEAR 1	YEAR 10
$1171 x	[20]	=	(.00)	(.00)
839 x	[21]	=	(.00)	(.00)
712 x	[22]	=	(.00)	(.00)
573 x	[23]	=	(11.46)	(11.46)
472 x	[24]	=	(18.88)	(14.16)
351 x	[25]	=	(42.12)	(38.61)
19 x	[26]	=	(15.58)	(15.96)
	C	=	$(88.04)/HR [73]	$(80.19)/HR [74]

ANNUAL OPERATING COST REDUCTION

		YEAR 1		YEAR 10
K•L =	[71]x[65]) =	(17,690)	[72]x[66] =	(166,818)
+C•L =	[73]x[67]) =	+(16,446)	[74]x[68] =	+(193,899)
S =		$ (34,136) [75]		$ (360,717) [76]

WORKSHEET #5
2/2

	YEAR 1	YEAR 10
ANNUAL PASSENGER DELAY REDUCTION		
352 seats x [20]	= (.00)	(.00)
236 seats x [21]	= (.00)	(.00)
144 seats x [22]	= (.00)	(.00)
122 seats x [23]	= (2.24)	(2.24)
89 seats x [24]	= (3.56)	(2.67)
46 seats x [25]	= (5.52)	(5.06)
8 seats x [26]	=+(6.56)	+(6.72)
(Seats per acft)	= (17.88)	(16.69)
x(load factor)	x(.45)	x(.50)
=(Pax per acft)	=(8.05) [77]	=(8.35) [78]
Annual Pax Hours Saved	=[77]x[69]	=[78]x[70]
	=(2,770.) [79] pax hrs	=(34,511) [80] pax hrs

as will now be described.

In order to estimate the average number of passengers on board for takeoffs, (assumed to be the same as for landings), the seating capacity data of Table 10 is employed. The number of available seats for each of the seven aircraft types is multiplied by the aircraft mix fraction for the type, developed in Worksheet #1. These weighted seating capacities are summed to give an average seating capacity for all types. The analyst then estimates the average load factor at the airport and multiplies the seats per aircraft by the load factors. The result is then multiplied by the total annual aircraft hours of delay reduction to give the annual savings of passenger time due to the investment. The calculation is carried out for the first and tenth years in which the investment is operational.

The final step in obtaining passenger delay reduction benefits is to multiply by the value of passenger time. A uniform value of $12.50 per hour is allowed for passenger time, in conformance with current (1976) usage by the Federal Aviation Administration.

4.3 TOTAL VALUE OF DELAY REDUCTION BENEFITS AT THE AIRPORT

The total of aircraft operating cost reduction and passenger delay reduction occurring at the airport due to the improvement is obtained on Worksheet #6, based on the results of Worksheet #5. These totals will be used in Section 7.

4.4 SAMPLE CALCULATION: AIRPORT BENEFITS

The total delay reduction due to the investment at YNG were estimated on page 3 of Worksheet #4, to be 344 aircraft hours in 1979 and 4,133 aircraft hours in 1988. These will now be converted to dollar benefits on Worksheet #5, using the formula given above in the text.

The coefficients K and C of average aircraft operating costs are obtained on page 1 of Worksheet #5 by multiplying the hourly operating cost for each type of aircraft by its mix fraction, and adding. Because of the lack of heavy jets at YNG, the costs are in the range of $80 to $112. It should be noted that both 1979 and

WORKSHEET #6
1/1

WORKSHEET #6: VALUE OF AIRPORT DELAY REDUCTION

	YEAR 1	YEAR 10
AIRCRAFT OPERATING COST REDUCTION	[75] = $(34,136)	[76] = $(360,717)
ANNUAL PASSENGER HOURS SAVED x $12.50/HR	[79] = (1,259) x $12.50	[80] = (14,630) x $12.50
ANNUAL PASSENGER DOLLAR BENEFIT	= $(15,737) [81]	= $(182,875) [82]
TOTAL AIRPORT BENEFIT OF INVESTMENT	= [75] + [81] = $(49,873) [83]	= [76] + [82] = $(543,592) [84]

1988 operating costs are expressed in current dollars.

When delay per year is multiplied by operating cost, the results are savings of $34,136 for 1979 and $360,717 for 1988, as seen on page 1 of Worksheet #5. The annual passenger delay reduction is then obtained on page 2 of Worksheet #5. First, the average seats per aircraft are calculated. These figures are substantially the same in 1988 as for 1979; a slight reduction occurs because of the increase in small aircraft expected. A slight increase in load factor, from 45 to 50 percent is projected by the analyst. The annual passenger hours saved, however, increase more than 10 times.

Finally, the total airport benefits of the investment are obtained on Worksheet #6 by adding the aircraft operating costs savings to the passenger delay savings (the latter at $12.50 per hour) to obtain $49,873. in 1979 and $543,592 in 1988. This 10/1 increase in annual savings is due mainly to the fact that the planned runway would avert major delays at YNG which would have occurred because of the projected increase in general aviation traffic in 1988.

5. ESTIMATE THE VALUE OF SYSTEM-WIDE DELAY REDUCTION

The system-wide benefits calculated here are those due to the reduction in gate departure lateness at the investment airport, and at those airports that are down-line from it. For simplicity, gate departure lateness will be termed B-Delay. Reduction of B-Delay results in a saving of time to those passengers waiting to board the delayed aircraft, but does not result in a reduction of aircraft operating costs.

5.1 PROCEDURE

The calculations for YEAR 1 and YEAR 10 are laid out in Worksheet #7. The procedure, which is the same for both years, will now be explained.

First, the average delay per operation is calculated <u>without</u> investment and <u>with</u> investment. The delay per operation is simply the average of delay per arrival and delay per departure, both of which were obtained in Section 2, items (53.) through (60.) of Worksheet #4.

Next, on page 2 of Worksheet #7, Figure 25 is used to obtain B-Delay for each aircraft type. The average delays per operation (85.), (86.), (87.), (88.) calculated above are located on the horizontal axis, and the B-Delays are read off the vertical axis for aircraft types 1, 2, 3, types 4, 5, type 6, and type 7. The results are entered onto page 2. The B-Delays <u>with</u> investment are subtracted from the B-Delays <u>without</u> investment and entered as the B-Delay <u>reduction</u> at the bottom of the page.

This is the central step in calculation of system benefits. The chart was obtained by simulation of the propagation of gate departure lateness arising from landing and takeoff delays at the subject airport. In determining the passenger hours lost in B-Delay, the simulation allowed for aircraft seating capacity, the size and number of down-line airports served by each aircraft type, and the load factors at those airports as a function of aircraft type and time of day. The simulation is described in Reference 2.

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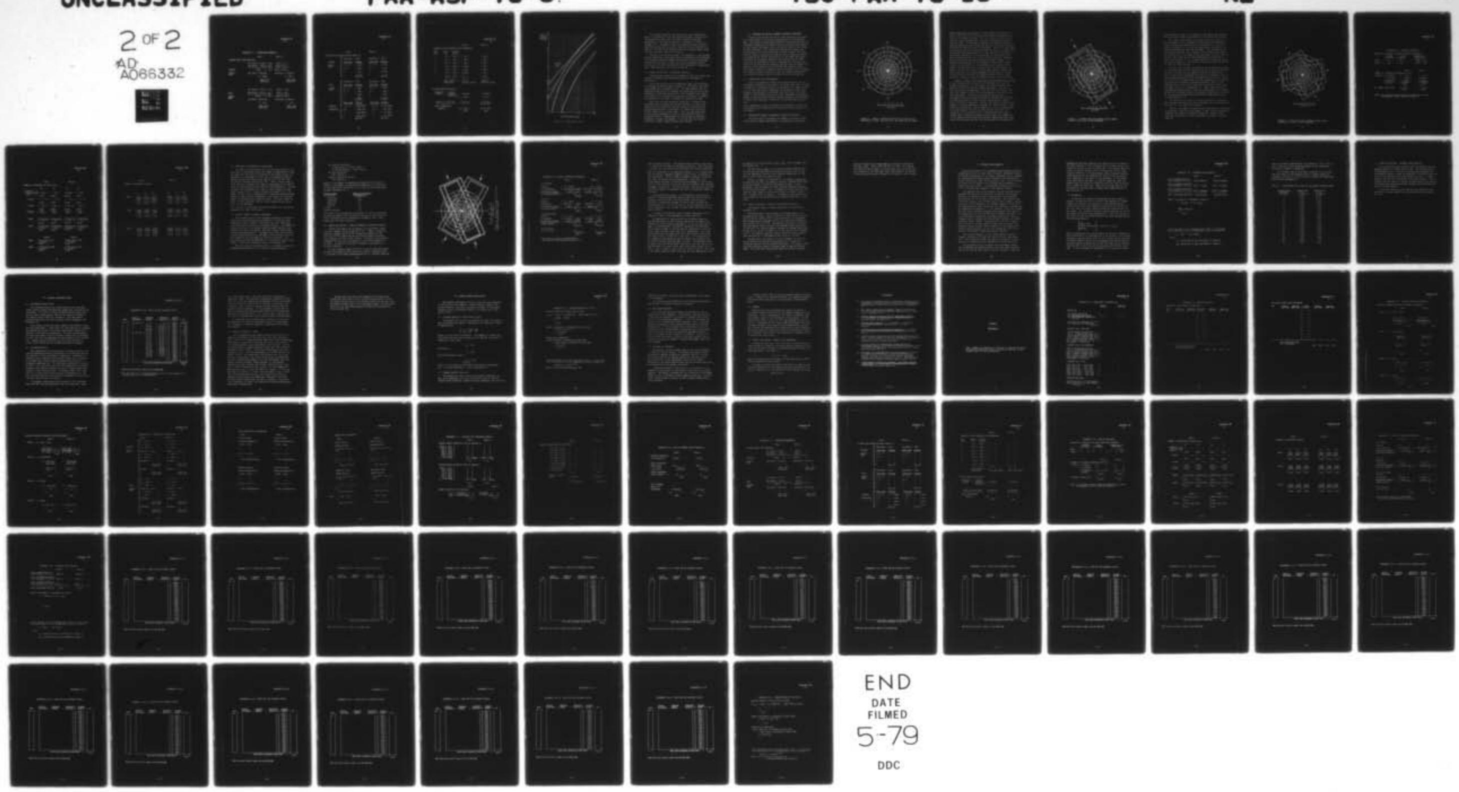

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WORKSHEET #7: SYSTEM-WIDE BENEFITS

AVERAGE DELAY PER OPERATION

	YEAR 1	YEAR 10
WITHOUT INVESTMENT	Arr Delay = [53] = (.35)	[54] = (1.7)
	Dep Delay = [55] = (.42)	[56] = (2.1)
	Total = (.77)	Total = (3.8)
	Avg Delay = ½(Total) = (.385) [85] min/operation	Avg Delay = ½(Total) = (1.90) [86] min/operation
WITH INVESTMENT	Arr Delay = [57] = (.19)	[58] = (.70)
	Dep Delay = [59] = (.23)	[60] = (.69)
	Total = (.42)	Total = (1.39)
	Avg Delay = ½(Total) = (.21) [87] min/operation	Avg Delay = ½(Total) = (.70) [88] min/operation

	YEAR 1		YEAR 10	

B-DELAY PER OPERATION FROM FIGURE 25

WITHOUT INVESTMENT +

Avg Delay = [85]		Avg Delay = [86]	
Acft Type	B-Delay	Acft Type	B-Delay
1, 2, 3	(.260)	1, 2, 3	(1.75)
4, 5	(.074)	4, 5	(1.15)
6	(.013)	6	(0.50)
7	(.000)	7	(.01)
	pax hrs		pax hrs

WITH INVESTMENT −

Avg Delay = [87]		Avg Delay = [88]	
Acft Type	B-Delay	Acft Type	B-Delay
1, 2, 3	(.100)	1, 2, 3	(.550)
4, 5	(.015)	4, 5	(.230)
6	(.000)	6	(.017)
7	(.000)	7	(.000)
	pax hrs		pax hrs

B-DELAY REDUCTION =

Acft Type	B-Delay	Acft Type	B-Delay
1, 2, 3	(.160) [89]	1,2,3	(1.20) [89]
4,5	(.059) [90]	4, 5	(.92) [90]
6	(.013) [91]	6	(.43) [91]
7	(.000) [92]	7	(.01) [92]
	pax hrs		pax hrs

WORKSHEET #7
3/3

				YEAR 1	YEAR 10

AVERAGE B-DELAY REDUCTION PER OPERATION

Acft Type	Sched. Mix		B-Delay Reduct.		YEAR 1	YEAR 10
1	[6]	x	[89]	=	(.000)	(.000)
2	[7]	x	[89]	=	(.000)	(.000)
3	[8]	x	[89]	=	(.000)	(.000)
4	[9]	x	[90]	=	(.0148)	(.276)
5	[10]	x	[90]	=	(.0265)	(.460)
6	[11]	x	[91]	=	(.0039)	(.086)
7	[12]	x	[92]	=	(.00)	(.000)
	AVG. B-DELAY REDUCTION			=	(.045) [93] pax hr/op	(.822) [94] pax hr/op

B-DELAY REDUCTION BENEFIT

				YEAR 1	YEAR 10
Scheduled Volume	x	Average B-Delay Reduction	=	[2]x[93]	[2]x[94]
			=	(450)	(11,015)
x(Value of Pax Time)				x($12.50)	x($12.50)
TOTAL SYSTEM-WIDE BENEFIT			=	$(5,625) [95]	$(137,685) [96]

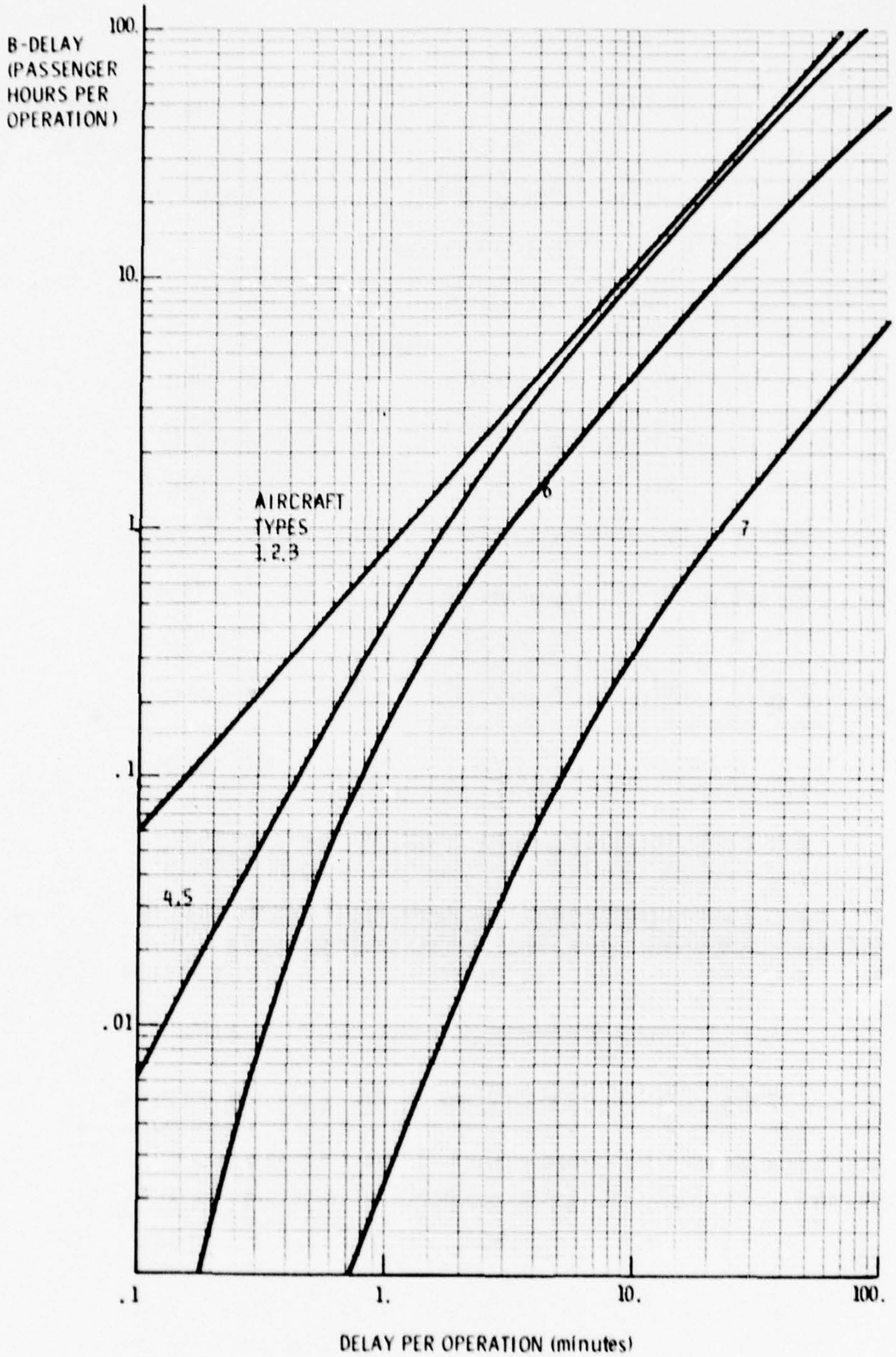

FIGURE 25. SYSTEM-WIDE B-DELAY

The B-Delay reductions for each aircraft type obtained on page 2 of Worksheet #7 are next combined on page 3 using the mix of scheduled aircraft types and annual volume of scheduled operations, as developed in Section 1, Worksheet #1, items (6.) through (12.). In general, both the scheduled aircraft mix and the B-Delay reduction by aircraft type will differ from YEAR 1 to YEAR 10. The sum of the products gives the average B-Delay reduction over aircraft types, for each year.

Finally, at the bottom of page 3 of Worksheet #7, the average B-Delay reductions in passenger hours per operation are multiplied by the annual scheduled volumes and the hourly value of passenger time to yield the total system-wide B-Delay reduction benefit, in dollars, for YEAR 1 and YEAR 10 of the investment's operational life. These results will be used in Section 7.

5.2 SAMPLE CALCULATION: SYSTEM-WIDE BENEFITS

Continuing the example of a new runway at YNG, the system-wide benefits of reduced gate departure delays are calculated on Worksheet #7.

First, the arrival delay and departure delay, per operation, are averaged to obtain a delay average of .385 minutes per operation without the investment in 1979. By 1988, however, this is expected to increase to 1.9 minutes per operation, as seen on the Worksheet #7 items (85.1) and (86.). The investment will reduce these losses to .16 minutes per operation in 1979 and .70 minutes per operation in 1979 and .70 minutes per operation in 1988.

Next, each of these delays per operation is located on the horizontal axis of Figure 25, and the vertical axis values are taken off of the curves for the four groups of aircraft types, and entered onto page 2 of Worksheet #7. Subtraction gives the B-Delay reduction by aircraft type. These are then multiplied by the relative frequency of each of seven aircraft types for scheduled traffic, from Worksheet #1, and entered at the top of Worksheet #7, page 3 and summed. It is seen that the B-Delay reduction in 1988 is about 20 times that in 1979.

6. ESTIMATE THE VALUE OF REDUCED AIRCRAFT DIVERSIONS

Aircraft occasionally must divert from landing at an airport due to high winds in a direction perpendicular to the approach path. New airport runways added primarily for capacity reasons are frequently aligned in a different direction from existing runways so that airport operations can be carried out under a wider range of wind conditions. This effectively reduces the expense and inconvenience of aircraft diverting to other airports, and these benefits should be considered along with delay reduction benefits in evaluating the overall desirability of the runway investment. The number of diversions reduced by the construction of a new runway can be estimated by jointly analyzing the historical patterns of wind direction and velocity together with the runway orientation of the airport with and without the proposed runway. The economic benefits of reducing these diversions can be estimated for different types of operations, and the resulting total diversion reduction benefits can be included in project evaluation.

6.1 AIRPORT WIND DATA REQUIREMENTS

Historical records of airport wind characteristics are conventionally displayed in the form of an airport wind rose, as shown in Figure 26. The wind direction is specified by 16 equal sectors of 22.5° and wind speed is indicated by concentric circles with diameters proportional to different wind velocities. The cells formed by the different circles and radii correspond to different ranges of direction and velocity, and the frequency of observation of these wind categories is shown by the data presented in each cell.

This information is used to estimate the percentage of operations occurring for each combination of wind direction and velocity at an airport.

6.2 CALCULATING CHANGES IN NUMBER OF AIRCRAFT DIVERSIONS

The first step in estimating the changes in aircraft diversions from new runway construction is an analysis of wind rose

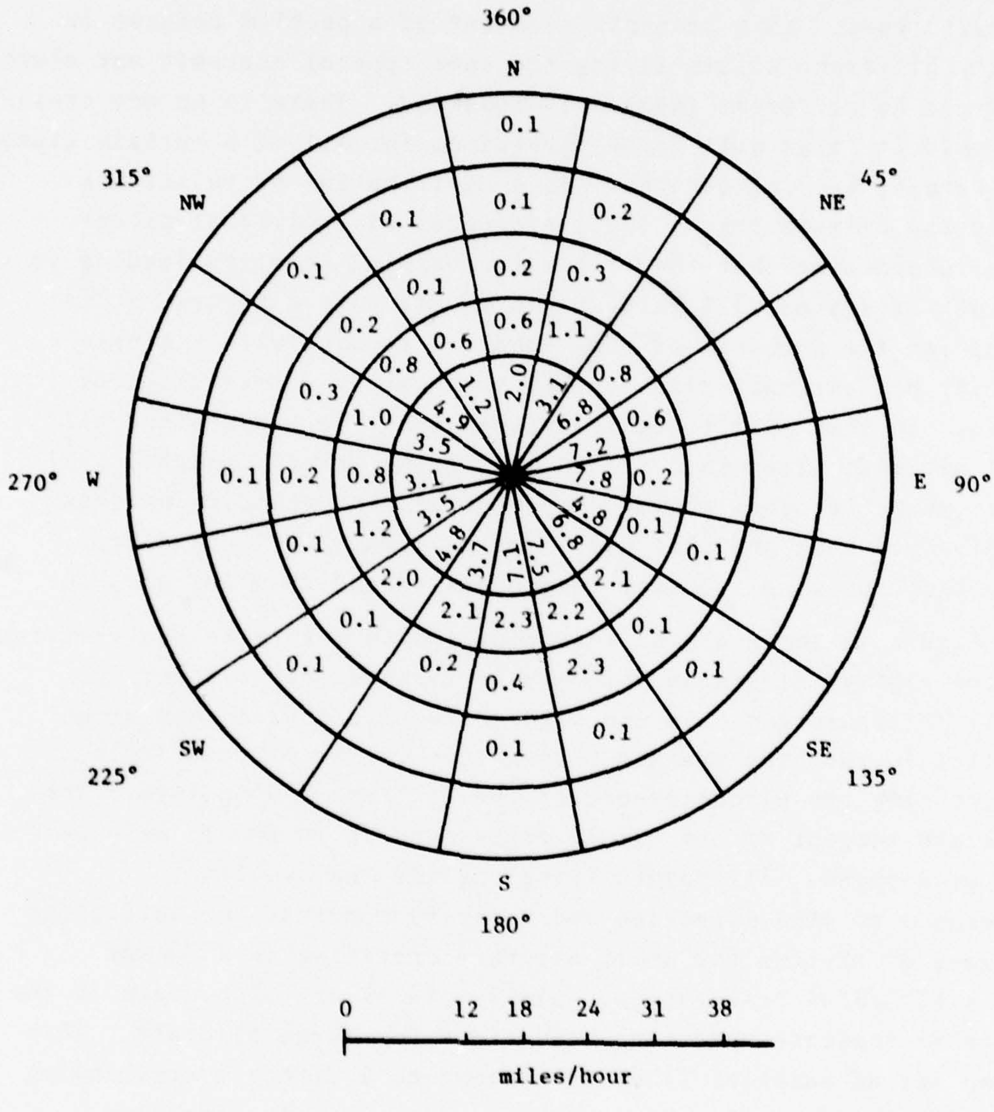

FIGURE 26. SAMPLE AIRPORT WIND ROSE (CELL ENTRIES ARE PERCENTAGE OF TIME, WIND VELOCITY, AND DIRECTION AS SHOWN)

data to determine the frequency of time different aircraft will divert, first with the existing airport runway configuration, and then for the runway in place. This will require selection of a critical crosswind speed that will cause diversions for specific aircraft types. This presents somewhat of a problem because in reality different pilots flying the same type of aircraft may elect to divert at different levels of crosswind. There is no one crosswind velocity that will cause diversions for all of a certain class of aircraft, but instead there is a distribution of velocities reflecting differences in the preferences of individual pilots. While recognizing that the critical crosswind velocity leading to aircraft diversion will vary within an aircraft category, it is useful for the purposes of this handbook to deal with a single velocity per aircraft class rather than with a distribution of values. In that spirit, it is assumed that for VFR weather all small aircraft (less than 12,500 lbs. gross takeoff weight) will divert when the cross runway component of wind velocity exceeds 15 miles per hour and that all larger aircraft will not divert until the crosswind velocity components exceed 23 miles per hour.

Figure 27 shows a wind rose modified to determine the fraction of time a given crosswind velocity is exceeded for a specific runway configuration. In the Figure, two lines have been drawn parallel to the line passing through the center of the circle and crossing the circumference at the 150° and 330° points. The lines are tangent to the circle corresponding to the 15 mile per hour wind speed. All points lying outside the two lines correspond to wind direction and velocity combinations sufficient to cause diversions for small aircraft operating on a runway with a 150°/330° orientation. Similar lines are also drawn in the Figure to indicate operating conditions for large aircraft. This second set of parallel lines is tangent to a circle corresponding to a wind speed of 23 miles per hour, and the lines are also oriented in a 150°/330°direction. The construction of a new runway with a different orientation would result in a reduction in the number of wind speed and direction combinations that could result in diversion, and this can be reflected by the addition of

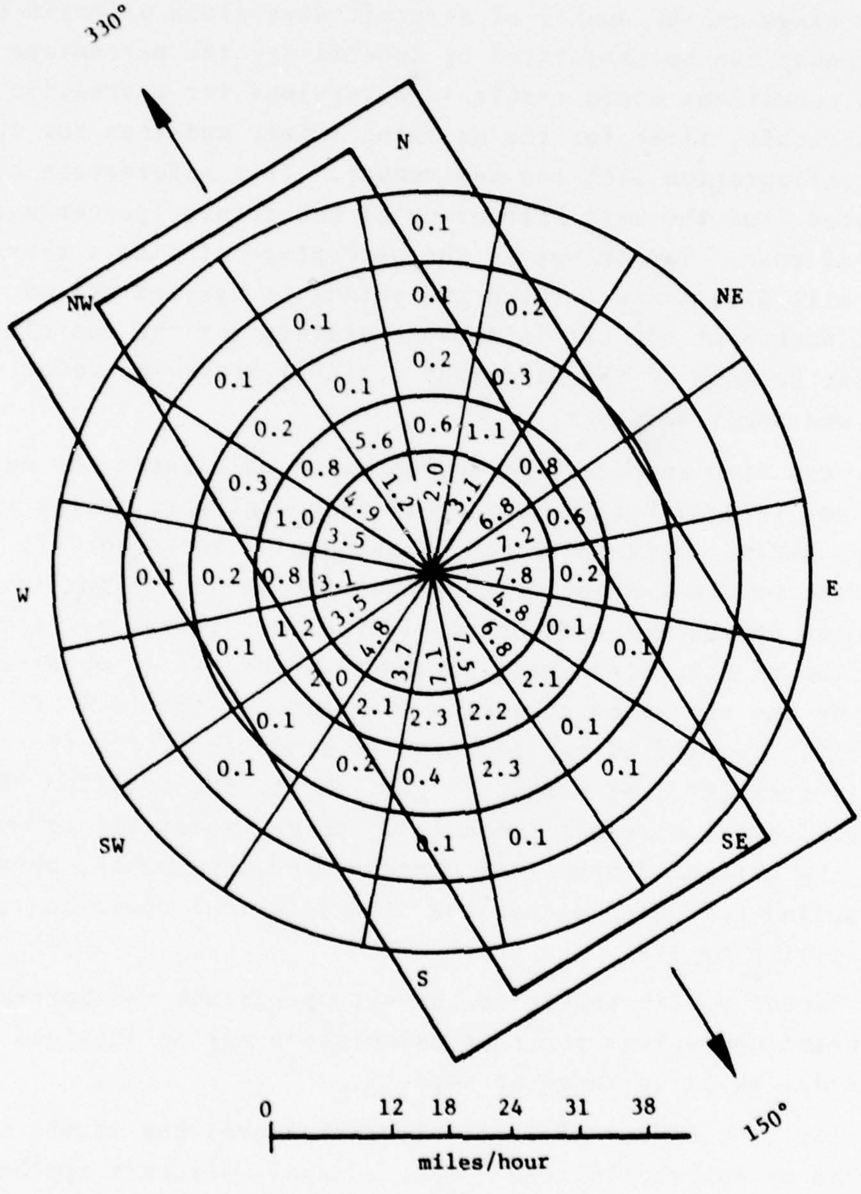

FIGURE 27. AIRPORT WIND ROSE SHOWING SINGLE RUNWAY COVERAGE FOR 15 AND 23 MPH CROSSWINDS

two new parallel lines, as in Figure 28, having the same orientation as the new runway and separated by the appropriate distance.

The change in the number of aircraft diversions affected by the new runway can be calculated by determining the percentage of time wind conditions would result in diversions for a specific type of aircraft, first for the existing runway and then for the airport configuration with the new runway. This information can be estimated from the cell "frequency of occurrence" percentages on the wind rose. The change in the percentage of time a class of aircraft will divert due to high crosswinds is carried out on page 1 of Worksheet #8. It is done separately for the two classes of aircraft because of the different critical crosswind velocities of large and small aircraft.

The next step on page 1 of Worksheet #8 calculates the number of small and large aircraft approaches at the airport, using total operations and mix data developed in Section 2, Worksheet #1. This is done on the assumption that only the itinerant portion of nonscheduled approaches need be considered for diversion. First, the fraction of scheduled small aircraft approaches is obtained by multiplying the estimated scheduled operations (item [2.] of Worksheet #1) by half of the fraction of scheduled aircraft that are small (item [12.] of Worksheet #1). Next, the fraction of nonscheduled small aircraft (item [19.] of Worksheet #1) is multiplied by the estimated number of nonscheduled approaches, obtained by subtracting scheduled operations from itinerant operations, and multiplying by 1/2.

The factor of 1/2 serves to convert operations to approaches. The itinerant operations for this calculation may be obtained from Reference 4., as illustrated on page 13.

Finally, the number of large aircraft approaches at the airport is obtained by subtracting the number of small aircraft approaches from half the number of itinerant operations. These calculations are carried out for YEAR 1 and YEAR 10 on page 1 of Worksheet #8.

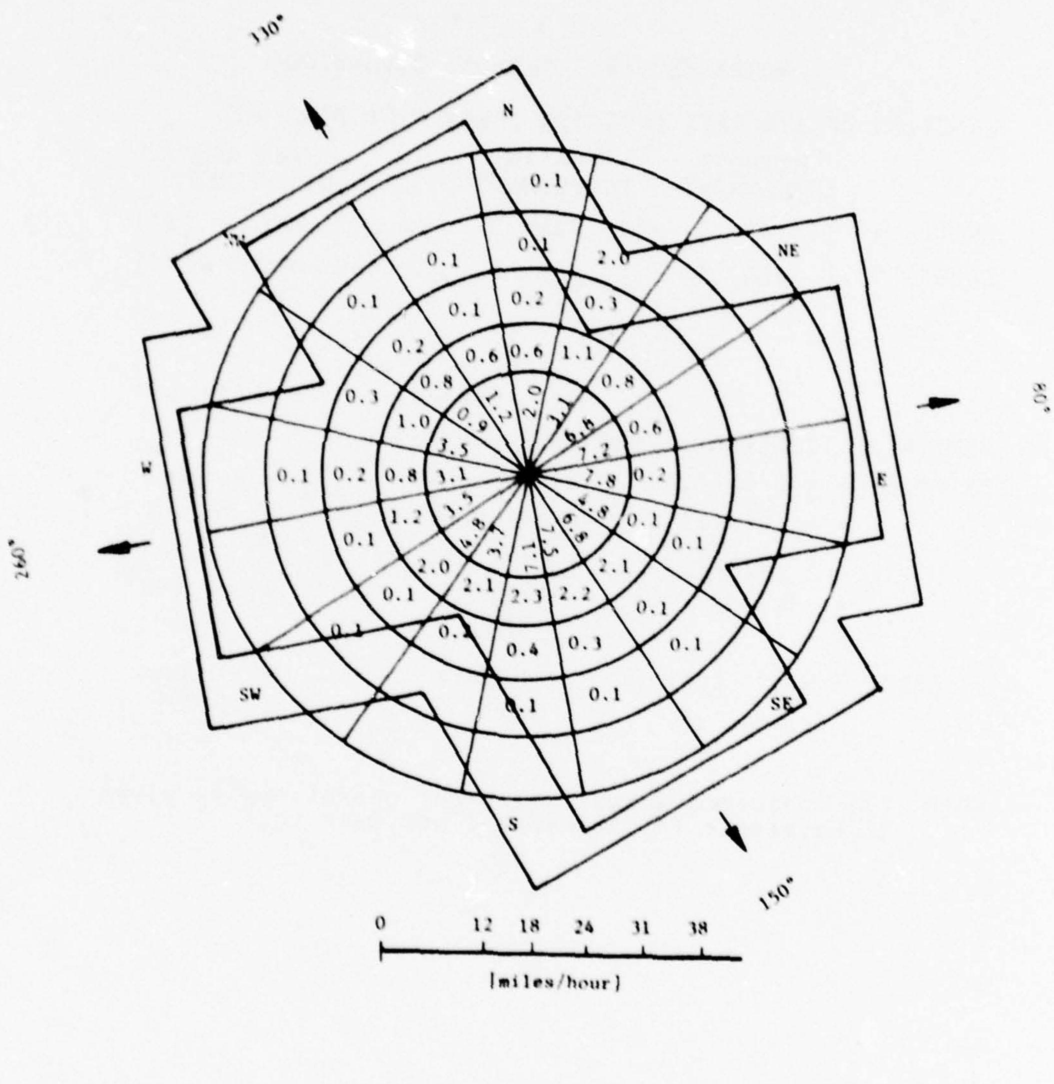

FIGURE 28. AIRPORT WIND ROSE SHOWING DOUBLE RUNWAY COVERAGE FOR 15 AND 23 MPH CROSSWINDS

WORKSHEET #8: REDUCED DIVERSIONS

FRACTION OF AIRCRAFT DIVERTED (FROM WIND DIAGRAM)

		WITHOUT INVESTMENT		WITH INVESTMENT		CHANGE DUE TO INVESTMENT		
SMALL	=	(.112)	-	(.024)	=	(.088)	=	[97]
LARGE	=	(.012)	-	(.008)	=	(.004)	=	[98]

		YEAR 1	YEAR 10
NUMBER OF ITINERANT APPROACHES BY SIZE			
BY SMALL	= ½ [2]x[12]	=(000)	=(000)
	+ ½ [I]x[19]	+(31,050)	+(50,310)
	- ½ [2]x[19]	-(4,500)	-(6,030)
	= (Total)	=(26,550) [99]	=(44,280) [100]
BY LARGE	= ½[I] - [99]	=(7,950) [101]	=(11,620) [102]

NOTE: [I] indicates annual Itinerant operations as given in Reference (4) for YEAR 1 and YEAR 10.

	YEAR 1		YEAR 10	
NUMBER OF APPROACHES BY USER CLASS				
	AC	AT	AC	AT
½ (Annual Operations Ref. 1) =	(4,500)	(500)	(6,200)	(500)
	[103]	[106]	[109]	[112]
% SMALL =	(0)%	(0)%	(0)%	(0)%
	[104]	[107]	[110]	[113]
% LARGE =	(100)%	(100)%	(100)%	(100)%
	[105]	[108]	[111]	[114]
% TOTAL =	100%	100%	100%	100%

SMALL	[103]x[104] = (0.0) [115]	[106]x[107] (0.0) [117]	[109]x[110] =(0.0) [119]	[112]x[113] (0.0) [121]
LARGE	[103]x[105] = (4,500) [116]	[106]x[108] (500) [118]	[109]x[111] =(6,200) [120]	[112]x[114] (500) [122]

	GA/MIL	GA/MIL
SMALL	[99]-[115]-[117] = (26,500) [123]	[100]-[119]-[121] =(44,280) [124]
LARGE	[101]-[116]-[118] = (2,950) [125]	[102]-[120]-[122] =(4,920) [126]

WORKSHEET #8

3/3

NUMBER OF DIVERSIONS AVERTED

	YEAR 1			YEAR 10		
	AC	AT	GM	AC	AT	GM
SMALL	[115] x[97] =(00) [127]	[117] x[97] =(00) [128]	[123] x[97] =(2336) [129]	[119] x[97] =(00) [130]	[121] x[97] =(00) [131]	[124] x[97] =(3897) [132]
LARGE	[116] x[98] =(18) [133]	[118] x[98] =(2) [134]	[125] x[98] =(12) [135]	[120] x[98] =(25) [136]	[122] x[98] =(2) [137]	[126] x[98] =(20) [138]
TOTAL	[127] +[133] (18) [139]	[128] +[134] (2) [140]	[129] +[135] (2348) [141]	[130] +[136] (25) [142]	[131] +[137] (2) [143]	[132] +[138] (3917) [144]

6.3 REDUCTION IN DIVERSIONS BY USER CLASS

In order to calculate the costs of diversions averted, it is necessary to break down further the number of approaches by large and small aircraft that were obtained at the bottom of page 1 of Worksheet #8. Approaches in these two size categories must be further divided into those of Air Carrier (AC), Air Taxi (AT) and General Aviation and Military (GM). This is done on page 2, where the user calculates the number of approaches for AC and AT based on the projected traffic obtained from Reference 4. He then estimates the percentage of AC that is small (usually 0%) and large (usually 100%). Similar estimates are made for AT. The number of small AC and AT approaches is subtracted from the total number of small aircraft approaches at the airport to yield the number of GM approaches by small aircraft. The same is done for large aircraft approaches and the results appear at the top of page 3 of the Worksheet.

As is seen in the Worksheet, the above estimates are carried out separately for YEAR 1 and YEAR 10.

6.4 VALUE OF REDUCED AIRCRAFT DIVERSIONS

The procedure used in this handbook to quantify the value of reduced aircraft diversions was developed in a previous study (Reference 7) and is based on the delays and costs associated with diverting an aircraft to a different airport. For commercial operations, these costs include added passenger handling costs, revenues lost due to subsequent cancelled flights, and aircraft repositioning expenditures. Passenger delay costs and increased aircraft operating costs are included in the diversion costs for both commercial and noncommercial aircraft operations. The calculations are done on Worksheet #9, based on the reduced total number of diversions obtained on page 3 of Worksheet #8.

The unit cost per diverted aircraft is estimated (using the methodology developed in "9" to take the following values:

Air Carrier Diversions

at Hub Airports - $550 + $148 n

at Non-Hub Airports - $506 + $148 n

Air Taxi Diversions

$30 + $96.50 n

General Aviation Diversions

$20 + $46.25 n

where n is the number of deplaning passengers on the affected flights. The analyst can evaluate the magnitude of n from fleet mix and load factor information or by using the following system averages [Reference 9]):

Type of Flight	Number of Deplaning Passengers, n
Air Carrier	
Large Hub	54.0
Medium Hub	38.1
Small Hub	29.7
Non-Hub	8.1
Air Taxi	6.3
General Aviation	5.0

The result of the calculation of Worksheet #9 will be an estimate of the total benefit due to reduced diversions at the airport in YEAR 1 and YEAR 10 of the investment's productive life. These results will be used in Section 7.

6.5 SAMPLE CALCULATION: CHANGE IN NUMBER OF AIRCRAFT DIVERTED

Consider once again the investment in an additional runway (12/30) to augment the existing one (7/25). Figure 29 shows the wind rose diagram with both the crosswind rectangles for the existing 70°/250° runway and the extentions produced by adding the rectangles for the 12°/300° runway. The width of the narrower rectangles in each case corresponds to a crosswind component of 15 knots. The width of the larger rectangles corresponds to a 23 knot crosswind.

For the original runway (70°/250°) it can be seen from Figure 29 that wind conditions fall outside the smaller rectangle about 11.2 percent of the time, producing about an 11.2 percent diversion

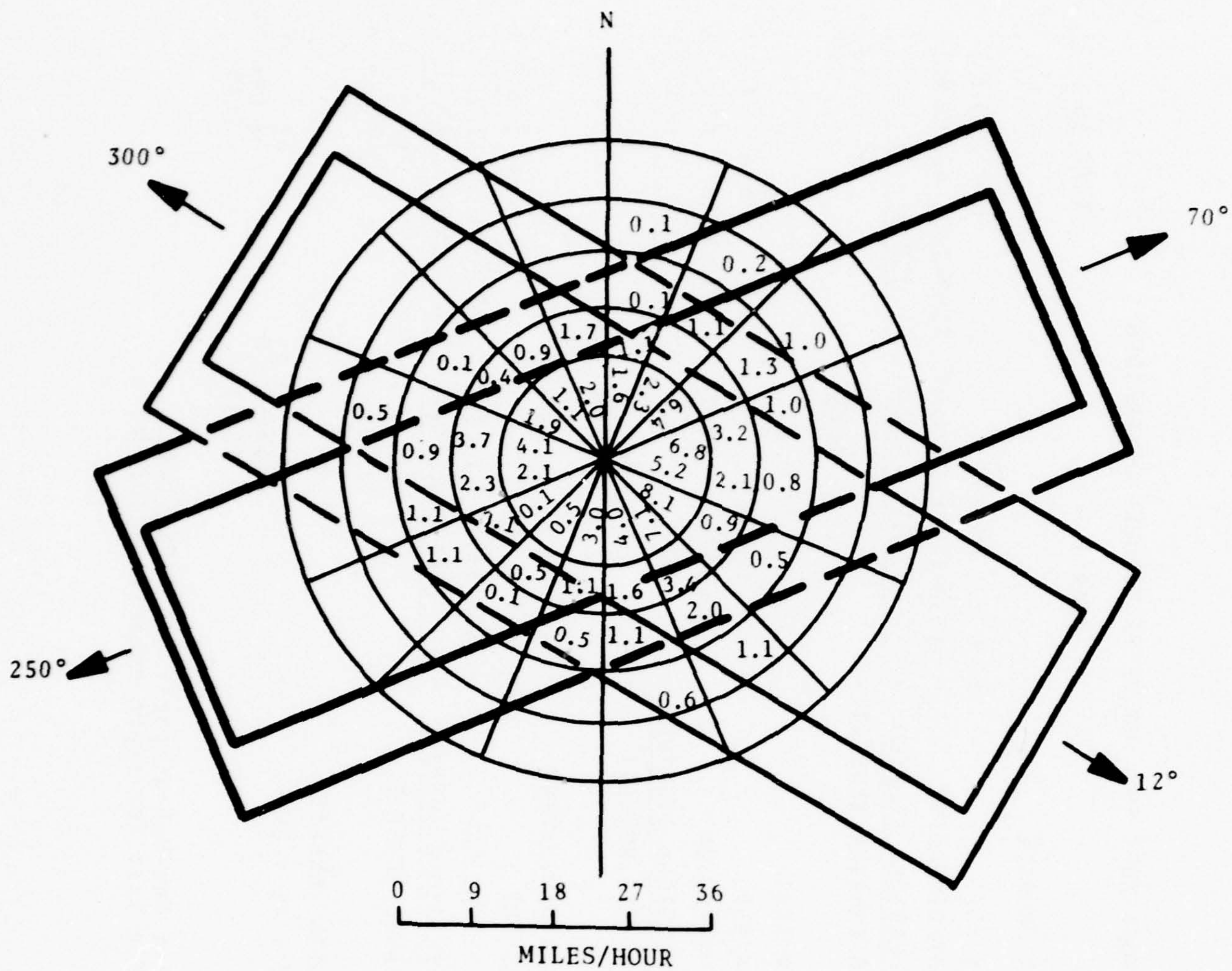

FIGURE 29. WIND ROSE FOR SAMPLE CALCULATIONS SHOWING DOUBLE RUNWAY COVERAGE

WORKSHEET #9: VALUE OF REDUCED DIVERSIONS

		YEAR 1	YEAR 10
AIR CARRIER			
PAX/FLT	=	n = (24.8)	n = (27.3)
COST/DIVERSION	=	\$550+\$148n=\$ (4220)*	\$550+148n =\$(4590)*
x DIVERSIONS AVERTED	=	[139] x(18)	[142] x(25)
AIR CARRIER BENEFIT	=	\$( ) 75,960	\$( ) 114,750
AIR TAXI			
PAX/FLT	=	n = (8.4)	n = (9.2)
\$/DIVERSION	=	\$30+\$97n = (845)	\$30+\$97n = (922)
x DIVERSIONS AVERTED	=	[140] x(2)	[143] x(2)
AIR TAXI BENEFIT	=	\$( ) 1690	\$( ) 1844
GA AND MILITARY			
PAX/FLT	=	n = (5.0)	n = (5.0)
\$/DIVERSION	=	\$20+\$46n = (250)	\$20+\$46n = (250)
x DIVERSIONS AVERTED	=	[141] x(2348)	[144] x(3917)
GA&MIL BENEFIT	=	\$( ) 587,000	\$( ) 979,000
TOTAL BENEFIT			
AC + AT + GM	=	\$(664,650) [145]	\$( ) 1,095,844 [146]

*For Non-Hub airports use \$506+\$148n
See text for representative values of n.

rate for small aircraft. For large aircraft, however, only about 1.2 percent of the time are diversions necessary. These fractions (.112 and .012) are entered onto Worksheet #8, without investment.

When the investment is in operation, however, it is estimated that the two smaller rectangles together cover all but 2.4 percent of wind conditions. The two larger rectangles, moreover, cover all but about .08 percent of wind conditions. (Note that it is occassionally necessary to prorate the percentages in a wind rose sector by the fraction of the area that is covered by the crosswind rectangle in question). The two fractions, .024 and .008, are also entered onto page 1 of Worksheet #8, and the differences taken as indicated.

The second step on page 1 of the Worksheet calculates the number of itinerant approaches made by small aircraft, using the itinerant operations data from the Terminal Area Forecasts, Reference 4, reproduced on page 13 and the small aircraft mix from Worksheet #1. For 1979 a total of 34,500 approaches (1/2 of 69,000 operations) will be made, of which about 26,550 will be by small aircraft.

In 1988, the projected 55,900 itinerant approaches will be composed of about 44,280 approaches by small aircraft.

The approaches by large aircraft are obtained simply by subtracting from the total itinerant approaches the number just obtained for small aircraft approaches. It will be seen that on page 2 of the Worksheet, the analyst determines from Reference 4 the expected number of carrier and taxi approaches in 1979 and enters these as items (103.) and (106.) respectively. For 1988 he estimates that the numbers will be 6,200 and 500 respectively and enters these as items (109.) and (112.). He then exercises his judgment to determine how each of these four estimates will be divided between large and small aircraft. The Worksheet shows he expects all carrier aircraft to be over 12,500 lbs. and all air taxi aircraft to be over 12,500 lbs. in both years (items [104.], [105.], [107.], [108.], [110.], [111.], [113.], [114.]). This leads to the values shown for small and large aircraft approaches in the

two years by air carrier and air taxi (items (115.) through (122.) on Worksheet #8).

The last step on page 2 is to obtain estimated General Aviation and Military approaches by subtracting the air carrier and air taxi approaches from the total estimated approaches for the year, for both small and large aircraft.

Finally, on page 3 of Worksheet #8, the number of approaches by Small Carrier, Taxi, and General Aviation is multiplied by the fractional change in diversions determined on page 1 of the Worksheet to get the number of small aircraft diversions averted by the three user types. This is repeated for large aircraft, and then the total number of diversions averted is obtained (items (139.) through (144.) on page 3). As expected, small General Aviation accounts for the vast majority of reduced diversions in both years.

6.6 SAMPLE CALCULATION: BENEFITS OF REDUCED DIVERSIONS

The economic value of reduced diversions is calculated on Worksheet #9.

The analyst must first estimate the average number, n, of passengers per flight. Based on statistics published for his airport by the air carriers and air taxis serving it, he estimates the average carrier passenger load to be 24.8 and the average air taxi load to be 8.4 in 1979. He considers these data to be reliable and employs them in place of the average values given above in the text. For 1988 an expected increase in average load factor brings the air carrier estimate to 27.3 and the air taxi estimate to 9.2. For general aviation, however, he has no other reliable data and uses the 5.0 passengers/flight given in the text.

Having entered the values of n onto Worksheet #9, the cost per diversion is calculated and multiplied by the number of diversions averted from the previous Worksheet. The result is the diversion reduction benefits for each class of user in 1979 and 1988. It is seen that the greatest benefits accrue to General

Aviation because of the large number of diversions averted for that user class: 2348 in 1979 and 3917 in 1988. As a result, the General Aviation benefit is seven times that of Carrier and Taxi combined in 1979 and eight times their benefits in 1988 due to the projected relative increase in GA traffic in the 10 years.

7. ESTIMATE TOTAL BENEFITS

Previous sections of this handbook have presented methods of estimating the size of three types of airport investment benefits. The overall desirability of an airport investment can be examined by combining the different types of benefits and comparing the result with project costs over the project life. In this section, the three types of benefits are combined and discounted to a single base year benefit. In subsequent sections, project costs will be estimated and compared to the combined benefits.

The approach used in the previous sections developed benefit estimates for the 1st and 10th years of project life because forecasts of important airport characteristics are generally projected only 10 to 12 years in the future. Most airport projects have economic lives greater than 10 years, however, and the objective of this handbook is to estimate benefits for 20 years. The methodology used here deals with this problem by introducing two simplifying assumptions. First, benefits in the 11th through the 20th years of project operation are assumed to be equal to the annual benefits for the 10th year of project operation. This is a conservative assumption since many airports will have increasing traffic volumes over time and most benefits are proportional to traffic volume. Annual benefits for these airports will continue to increase after the 10th year of project life because of normal airport traffic growth, so the assumption of constant annual benefits for the 10th through the 20th year of project life probably understates project benefits.

The second assumption is that annual benefits increase linearly between the 1st and 10th years of project operating life. This assumption allows the analyst to estimate 10-year benefits by examining airport operations for only two years.

The procedure used to estimate total investment benefits uses a mathematical formula based on the total annual benefits for the 1st and the 10th years of project operation. When the

mathematics have been completed, the analyst has an estimate of the total benefits of the investment over a 20-year period, discounted to the first year of project use. The formula implicitly uses a 10 percent interest rate to discount the 20-year time stream of benefits to the net present value of project benefits. These benefits will be compared with the net value of project costs developed in Section 8 of this handbook. If the project costs begin before the YEAR 1 of project operation, then the benefits must be further discounted to the first year of project costs, termed the Base Year. When both costs and benefits are discounted to the Base Year, a benefit/cost comparison may be made (Section 9.)

7.1 METHODOLOGY

To describe the method of evaluating the time stream of benefits, assume that at this point in the handbook the airport planner has evaluated the benefits of reducing runway delay, aircraft diversions, and system-wide airport delays for the 1st and 10th years of airport operation after the construction of a new runway. The estimated savings resulting from the use of the new runway are entered onto Worksheet #10. The total savings for the first 20 years of airport operation are then estimated using the following equation:

$$\begin{bmatrix} \text{Twenty-Year} \\ \text{Airport Operation} \\ \text{Benefits} \end{bmatrix} = 3.96\ B_1 + 5.40\ B_{10}$$

where B_1 and B_{10} are the total benefits of the new investment for YEAR 1 and YEAR 10 of investment use at the airport. The formula develops a time-discounted total of the 20-year stream of airport investment benefits based on the assumption that annual benefits increase linearly from the 1st to the 10th year and are constant from the 10th to the 20th year of operation with the new investment. It also includes the assumption of a 10 percent discount

WORKSHEET #10: ESTIMATE TOTAL BENEFITS

	YEAR 1	YEAR 10
TOTAL AIRPORT BENEFITS from Worksheet #6, p 1/1	[83] =$ (49,873)	[84] =$ (543,592)
TOTAL SYSTEMWIDE BENEFITS from Worksheet #7, p 3/3	[95] = (5,625)	[96] = (137,685)
TOTAL DIVERSION BENEFITS from Worksheet #9, p 1/1	[145] = (664,650)	[146] = (1,095,844)
TOTAL INVESTMENT BENEFITS	B_1 =$ (720,148)	B_{10} =$ (1,777,121)

TWENTY YEAR BENEFIT, DISCOUNTED TO YEAR 1*

$$= 3.96x(B_1) + 5.40 \times (B_{10})$$

= ($12,448,000)
[149]

* This formula is for a discount rate of 10%. If a discount rate other than 10% is to be employed, then the formula is:

$$C_1 \times (B_1) + C_{10} \times (B_{10})$$

where

C_1 = coefficient of B_1 from Table 11, page 111.

C_{10} = coefficient of B_{10} from Table 11, page 111.

rate, prescribed by OMB Circular A-94, March 27, 1972. The result is the net 20-year operating benefit of the investment, discounted to YEAR 1 of operation.

If a discount rate of other than 10 percent is to be used, then the values in the following Table 11 should replace the constants 3.96 and 5.40 in the preceding formula for Twenty-Year Airport Operation Benefits.

TABLE 11. COEFFICIENTS OF B_1 AND B_{10} FOR VARIOUS DISCOUNT RATES

Discount Rate (percent)	Coefficient of B_1	Coefficient of B_{10}
1	4.87	13.36
2	4.75	11.93
3	4.63	10.69
4	4.52	9.61
5	4.42	8.67
6	4.32	7.84
7	4.22	7.12
8	4.13	6.47
9	4.04	5.91
10	3.96	5.40
11	3.88	4.96
12	3.81	4.56
13	3.74	4.20
14	3.67	3.88
15	3.60	3.60
16	3.54	3.34
17	3.48	3.12
18	3.42	2.89
19	3.37	2.70
20	3.31	2.53

7.2 SAMPLE CALCULATION: ESTIMATE TOTAL BENEFITS

It is now possible to calculate the total benefits for the proposed addition of runway 12/30 at YNG. The dollar benefits from Worksheets #6, #7, and #9 are entered onto Worksheet #10. The greatest benefits accrue to reductions in aircraft diversions, which are 92 percent of the total benefits in 1979. In 1988, however, they are only 61 percent of the total benefit. This is because diversion benefits increase in proportion to the traffic, but airport and system-wide delays increase even more rapidly as traffic exceeds capacity.

The 20-year benefits of $12,456,000 are obtained by multiplying the 1st year benefit by 3.96 and the 10th year benefit by 5.40.

8. ESTIMATE INVESTMENT COSTS

8.1 INVESTMENT PROJECT COSTS

The estimated project cost should reflect the total additional airport capital and operating expenditures required by the investment. If a cost or receipt includes projects other than the one under consideration, then only the portion related to the present project should be considered. This may require prorating some costs for land, taxiways, safety equipment, and drainage, etc.

Costs should include all funds spend by both Federal, state, and local governments. Funds spent for land acquisition, planning and engineering services, and actual construction should be included in total capital expenditures. The costs of maintenance and recurring repairs for the investment should also be included for each year when the magnitude of these expenses can be estimated. Landing, rental and other fees to be paid directly by airport users should also be included each year as revenue.

8.2 DISCOUNTING COSTS

When expenditures are projected over a number of years, the various expenditures must be discounted to the same Base Year as the benefits to allow cost/benefit comparisons. Worksheet #11 should be used to tabulate and discount project costs, starting in the Base Year B and continuing through the 20th year of investment operating life. The investment operating life starts at YEAR 1, the first full year that the construction is complete enough to incur benefits (whether or not it actually does), and extends 20 years from that date. In general, YEAR 1 will occur from 0 to 5 years after the Base Year B on Worksheet #11. The last year for which costs are entered on Worksheet #11 must coincide with the 20th year after YEAR 1.

For example, assume construction starts in 1978, the Base Year, and that the new runway goes into use in May 1981. Since

WORKSHEET #11.10**

WORKSHEET #11.10 COSTS FOR 10% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+	OPERATING EXPENSE	—	OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(4,500,000	+	0	—	0)	x	1.0000	=	(4,500.0)
( )	(		18,000	—	8,000)	x	.9090	=	(9.1)
( )	(		40,000	—	20,000)	x	.8264	=	(16.5)
( )	(		40,000	—	25,000)	x	.7513	=	(11.3)
( )	(		40,000	—	30,000)	x	.6830	=	(6.8)
( )	(		40,000	—	32,000)	x	.6209	=	(5.0)
( )	(200,000	+	40,000	—	34,000)	x	.5644	=	(116.4)
( )	(		40,000	—	36,000)	x	.5131	=	(2.1)
( )	(		40,000	—	36,000)	x	.4665	=	(1.9)
( )	(		40,000	—	36,000)	x	.4241	=	(1.7)
( )	(		40,000	—	36,000)	x	.3855	=	(1.5)
( )	(		40,000	—	38,000)	x	.3504	=	(.7)
( )	(		40,000	—	38,000)	x	.3186	=	(64.4)
( )	(		40,000	—	38,000)	x	.2896	=	(.6)
( )	(		40,000	—	39,000)	x	.2633	=	(.3)
( )	(		40,000	—	39,000)	x	.2393	=	(.2)
( )	(		40,000	—	39,000)	x	.2176	=	(.2)
( )	(		40,000	—	40,000)	x	.1978	=	(.0)
( )	(		40,000	—	40,000)	x	.1798	=	(36.0)
( )	(		40,000	—	40,000)	x	.1635	=	(.0)
( )	(		40,000	—	40,000)	x	.1486	=	(.0)
( )	(				)	x	.1351	=	( )
( )	(				)	x	.1228	=	( )
( )	(				)	x	.1116	=	( )
			TOTAL COSTS DISCOUNTED TO BASE YEAR *					=	(4,774.7) [150]

*The first year listed is taken to be the BASE YEAR

**See Worksheet #11.1 through Worksheet #11.20 in the Appendix for discount factors of 1% through 20%.

use starts before July 1, the first full year of operation is taken to be 1981. The 20th year of operation, therefore, is the year 2000. The cost tabulation on Worksheet #11 will accordingly start in 1978 (first year of costs) and end in 2000 (last year of benefit life). Benefits and costs beyond the year 2000 are ignored in the calculation. If the tabulation of Worksheet #11 must be extended, succeeding discount factors may be obtained by dividing the previous one by 1.10. In most cases, however, the 20th year of operation will occur before the end of the Worksheet.

If a discount rate of other than 10 percent is to be used, then Worksheet #11 should be replaced by one of the Worksheets 11-1 through 11-20 from the Appendix, depending on the discount rate employed.

8.3 SAMPLE CALCULATION: COSTS

For the hypothetical new runway construction at YNG, it is supposed on Worksheet #11 that the first costs are incurred in 1978. These costs include planning, land acquisition, engineering, construction, relocation of existing facilities, security and fire/crash equipment, and installation of new taxiways. In 1979 the construction is completed and the runway goes into operation; therefore, 1979 is YEAR 1. Only partial maintenance costs are incurred in 1979. The full maintenance cost at $40,000/year commences in 1980. The runway must be resurfaced every six years, at a cost of $200,000. This shows as additional investment but could be considered maintenance if no net improvement (grooving, special surface treatment, added drainage) is contemplated. Operating receipts increase with traffic from $20,000 per (full) year in 1980 to $40,000 per year in 1998. In this example the Base Year for costs is 1978, the YEAR 1 of benefits is 1979, and the YEAR 10 of benefits is 1988. The 20th benefit year is 1998. Costs and benefits that accrue to the project after 1998 are ignored in the benefit/cost comparison. Because of the small discount factors beyond 1998, the loss in accuracy is not excessive, especially in view of the difficulty of predicting expenses and benefits beyond 1998.

Having listed the costs and revenues from the Base Year through the 20th benefit year, a direct multiplication of their net amount for each year by the discount factor for the year gives the present values shown in the right-hand column. The sum of the entries in the right-hand column is the net cost discounted to 1978, the Base Year.

9. EVALUATE BENEFIT/COST RATIO

The benefits developed in Section 7 and the costs developed in Section 8 are now compared. Before doing so, however, the project benefits, which were discounted to YEAR 1 of investment operation, must be discounted further to the Base Year of the project costs.

9.1 DISCOUNT BENEFITS TO BASE YEAR OF COSTS

If the Base Year of costs t_B precedes the YEAR 1 of benefits, then the Twenty-Year Benefit of Worksheet #10, item (149.), must be multiplied by

$$\left[\frac{1}{1.10}\right]^{\left(t_1 - t_B\right)}$$

where t_1 is the YEAR 1 of benefits. For example, if runway construction costs are first incurred in 1979 but the first year of operation is 1981, then

$$t_B = 1979$$

and YEAR 1 is

$$t_1 = 1981$$

and the adjustment factor is

$$\frac{1}{(1.10)^2} = .826$$

which is to be applied to the Twenty-Year Benefit of Worksheet #10. The above adjustment is done on Worksheet #12.

9.2 COMPARE BENEFITS AND COSTS

The benefit/cost ratio is next calculated on Worksheet #12. This ratio represents the total of the three types of benefits (airport delay reduction, system-wide delay reduction, and diversion

WORKSHEET #12: COMPARE BENEFITS AND COSTS

DISCOUNT BENEFITS TO BASE YEAR OF COSTS

$t_1 - t_B$ = (YEAR 1 OF BENEFITS) - (BASE YEAR OF COSTS)
= (1979) - (1978)
= (1)
[151]

TWENTY YEAR BENEFIT, DISCOUNTED TO BASE YEAR*
= [149] $/(1.10)^{t_1 - t_B}$
= (11,324,000)
[152]

BENEFIT/COST COMPARISON
[TOTAL BENEFITS, DISCOUNTED TO BASE YEAR
÷ TOTAL COSTS, DISCOUNTED TO BASE YEAR]
= [152]/[150]
= (1.55)

* This formula is for a discount rate of 10% . If a discount rate other than 10% is to be employed, then the formula is:

$$[149]/(1. + R/100)^{t_1 - t_B}$$

Where R is the percent discount rate.

reduction) divided by the total costs attributable to the capacity investment.

In interpreting the benefit/cost ratio unaccounted benefits and accuracy of estimates should be considered.

9.3 UNACCOUNTED BENEFITS

The investment may have benefits and disbenefits not accounted for by this handbook. In particular, the user may have to consider the reduction or increase of aircraft noise experienced by the surrounding communities. Also, the investment may result in new terminal area traffic patterns, with a resultant decrease or increase in the average distance flown in approach and departure. If this distance can be converted to time lost or gained, it may be multiplied by operating costs and passenger time coefficients (K and C of Section 4) and then by traffic level to estimate its net benefit or disbenefit. Finally, the effect of the investment on local air and water quality and its synergistic effects on community economic development have not been included.

9.4 ACCURACY OF ESTIMATES

The accuracy of the estimates made by use of this handbook is limited by several factors. The underlying computer models are based on numerous assumptions regarding capacity, airspace utilization, the use of average quantities, and other aspects which contribute to the approximate nature of the results. Nevertheless, the models employed are far more detailed than could be accomplished by any manual calculation.

A large determinant of the accuracy of the results of this handbook is the accuracy of the capacity and traffic projections employed. The delays calculated are very sensitive to the demand/capacity ratio, particularly under congested conditions, and every effort should be made to employ the most accurate demand predictions available.

Finally, the accuracy of the cost estimates must be considered. In particular, operating revenues are largely dependent on projected traffic and subject to the accuracy of those projections.

9.5 SUMMARY

Benefit/cost ratios substantially above 1.00 provide a reasonably reliable indication of the economic soundness of the investment. Ratios substantially less than 1.00 indicate that the economic value of the investment is questionable. If the benefit/cost ratio is close to 1.00 (say, between .80 and 1.2) then it is advisable to take into account the benefits that have not been included in the analysis as discussed above, as well as to refine the demand and cost predictions as far as possible. The result should be considered a guide to the economic value of the investment rather than a final indication to proceed or not to proceed with the project.

9.6 SAMPLE CALCULATION: BENEFIT/COST COMPARISON

Because the Base Year, 1978, for costs is one year earlier than the YEAR 1 of benefits, the total benefits obtained as item (149.) on Worksheet #10 must be discounted from 1979 (YEAR 1) to 1978 (Base Year). The factor is

$$1/(1.1)^1 = .9091$$

and the 20-year benefits discounted to the base year are .9091 times $12,448,000 or $11,316,000.

In order to obtain the benefit/cost ratio, as shown at the bottom of Worksheet #10, the analyst divides $11,316,000 by the total discounted costs from Worksheet #11 and obtains the ratio:

benefit/cost =

REFERENCES

[1] The Airport Performance Model - Extensions, Validation and Application, Report FAA-ASP-78-10, Vol. I, II, U.S. Department of Transportation, Transportation Systems Center, September, 1977.

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[3] Airport Capacity Criteria Used in Long-Range Planning, U.S. Department of Transportation, Federal Aviation Administration, December 1969.

[4] Terminal Area Forecast, U.S. Department of Transportation, Federal Aviation Administration. (Various editions).

[5] UG3RD Baseline And Implementation Scenarios, U.S. Department of Transportation, Federal Aviation Administration, January 1977.

[6] Airport Activity Statistics of Certificated Route Air Carriers, prepared jointly by the U.S. Department of Transportation, Federal Aviation Administration, and the Civil Aeronautics Board (Various editions).

[7] Ceiling-Visibility Climatological Study and System Enhancement Factors, prepared by the National Climatic Center for the U.S. Department of Transportation, Federal Aviation Administration, June 1975.

[8] Procedures for Determination of Airport Capacity, prepared by Douglas Aircraft Company in Association with Peat, Marwick, Mitchell & Co., Mc Donnell Douglas Automation Company, and American Airlines for the U.S. Department of Transportation, Federal Aviation Administration, May 1975.

[9] Establishment Criteria for Category I Instrument Landing System (ILS), U.S. Department of Transportation, Federal Aviation Administration, March 1975.

APPENDIX

WORKSHEETS

Note: Numbers in brackets [ ] are used to identify important intermediate quantities, most of which are employed at subsequent points in the calculations.

WORKSHEET #1: OPERATIONS & WEATHER DATA

	YEAR 1 ( )	YEAR 10 ( )
OPERATIONS		
[1] =Total Operations =		
[2] =Scheduled Operations =	______	______
[3] =Non-Scheduled Operations =[1]-[2] =		
[4] =Fraction Scheduled [2]/[1] =	.	.
[5] =Fraction Non-Scheduled [3]/[1] =	.	.
AIRCRAFT MIX, SCHEDULED		
[6] =4 engine Wide Body Jet =	.	.
[7] =2, 3 engine Wide Body Jet =	.	.
[8] =4 engine Standard Body Jet =	.	.
[9] =3 engine Standard Body Jet =	.	.
[10] =2 engine Standard Body Jet =	.	.
[11] =Large Turboprop, Piston =	.	.
[12] =Small (<12,500 lb) =	.	.
AIRCRAFT MIX, NON-SCHEDULED		
[13] =4 engine Wide Body Jet =	.	.
[14] =2, 3 engine Wide Body Jet =	.	.
[15] =4 engine Standard Body Jet =	.	.
[16] =3 engine Standard Body Jet =	.	.
[17] =2 engine Standard Body Jet =	.	.
[18] =Large Turboprop, Piston =	.	.
[19] =Small (<12,500 lb) =	.	.
AIRCRAFT MIX, TOTAL		
[20] = [4] x [6] + [5] x [13] =	.	.
[21] = [4] x [7] + [5] x [14] =	.	.
[22] = [4] x [8] + [5] x [15] =	.	.
[23] = [4] x [9] + [5] x [16] =	.	.
[24] = [4] x [10] + [5] x [17] =	.	.
[25] = [4] x [11] + [5] x [18] =	.	.
[26] = [4] x [12] + [5] x [19] =	.	.
WEATHER FRACTIONS		
[27] =Fraction f_I of IFR weather =	.	.
[28] =Fraction f_V of VFR weather = (1.0-[27])	.	.

WORKSHEET #2: PROCESSING RATES

PROCESSING RATES WITHOUT INVESTMENT

RWY CONF.	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR	$\times \left(\frac{\%\ USE}{100} \right) =$	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
					x( ) =				
NET PROCESSING RATES WITHOUT INVESTMENT =						[29]	[30]	[31]	[32]

WORKSHEET #2
2/2

PROCESSING RATES WITH INVESTMENT

RWY	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR	x ($ USE / 100)	YEAR 1 VFR	YEAR 1 IFR	YEAR 10 VFR	YEAR 10 IFR
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
					x ( ) =				
NET PROCESSING RATES WITH INVESTMENT =						[33]	[34]	[35]	[36]

WORKSHEET #3: AIRPORT CONGESTION MEASURES

QUANTIFY RUNWAY CONGESTION, WITHOUT INVESTMENT

	YEAR 1	YEAR 10

STEP 1: $\bar{p} = f_I p_I + f_v p_V$

YEAR 1	YEAR 10
[27] x [30] = ( )	[27] x [32] = ( )
+ [28] x [29] = ( )	+ [28] x [31] = ( )
$\bar{p}$ = total = ( )	$\bar{p}$ = total = ( )
[37]	[38]

STEP 2: $\rho = V_T/(8760.\bar{p})$

YEAR 1	YEAR 10
$\rho = \frac{[1]\ \text{yr } 1.}{8760\cdot[37]}$	$\rho = \frac{[1]\ \text{yr } 10}{8760\cdot[38]}$
$= \frac{(\quad)}{8760\cdot(\quad)}$	$= \frac{(\quad)}{8760\cdot(\quad)}$
= ( )	= ( )
[39]	[40]

STEP 3: $r = P_I/P_v$

YEAR 1	YEAR 10
r = [30] / [29]	r = [32] / [31]
= ( )/( )	= ( )/( )
= ( )	= ( )
[41]	[42]

STEP 4: $\gamma = V_N/V_T$

YEAR 1	YEAR 10
γ = [5] yr 1	γ = [5] yr 10
= ( )	= ( )
[43]	[44]

QUANTIFY RUNWAY CONGESTION, WITH INVESTMENT

	YEAR 1	YEAR 10
STEP 1: $\bar{p} = f_I p_I + f_V p_V$		
	[27] x [34] = ( )	[27] x [36] = ( )
	[28] x [33] = ( )	[28] x [35] = ( )
	$\bar{p}$ = total = ( ) [45]	$\bar{p}$ = total = ( ) [46]
STEP 2: $\rho = V_T/(8760 \cdot \bar{p})$		
	$\rho = \frac{[1]\ \text{yr 1}}{8760 \cdot [45]}$	$\rho = \frac{[1]\ \text{yr 10}}{8760 \cdot [46]}$
	$= \frac{(\quad)}{8760\ (\quad)}$	$= \frac{(\quad)}{8760\ (\quad)}$
	= ( ) [47]	= ( ) [48]
STEP 3: $r = P_I/P_V$		
	r = [34]/[33]	r = [36]/[35]
	= ( )/( )	= ( )/( )
	= ( ) [49]	= ( ) [50]
STEP 4: $\gamma = V_N/V_T$		
	γ = [5] yr 1	γ = [5] yr 10
	= ( ) [51]	= ( ) [52]

WORKSHEET #4: RUNWAY DELAY REDUCTIONS

	YEAR 1	YEAR 10
WITHOUT INVEST-MENT	V_s = [2] = ( )	V_s = [2] = ( )
	f_v = [28] = ( )	f_v = [28] = ( )
	r = [41] = ( )	r = [42] = ( )
	Figures____and____	Figures____and____
	γ = [43] = ( )	γ = [44] = ( )
	ρ = [39] = ( )	ρ = [40] = ( )
	Arr Delay = ( ) [53] min/ operation	Arr Delay = ( ) [54] min/ operation
	Dep Delay = ( ) [55] min/ operation	Dep Delay = ( ) [56] min/ operation
WITH INVEST-MENT	V_s = [2] = ( )	V_s = [2] = ( )
	f_v = [28] = ( )	f_v = [28] = ( )
	r = [49] = ( )	r = [50] = ( )
	Figures____and____	Figures____and____
	γ = [51] = ( )	γ = [52] = ( )
	ρ = [47] = ( )	ρ = [48] = ( )
	Arr Delay = ( ) [57] min/ operation	Arr Delay = ( ) [58] min/ operation
	Dep Delay = ( ) [59] min/ operation	Dep Delay = ( ) [60] min/ operation

DELAY REDUCTION PER OPERATION

YEAR 1

Arrival Delay
Reduction/Operation
= [53] - [57]
= (   )
- (   )

= (   )
[61] min/operation

YEAR 10

Arrival Delay
Reduction/Operation
= [54] - [58]
= (   )
- (   )

= (   )
[62] min/operation

Departure Delay
Reduction/Operation
= [55] - [59]
= (   )
- (   )

= (   )
[63] min/operation

Departure Delay
Reduction/Operation
= [56] - [60]
= (   )
- (   )

= (   )
[64] min/operation

ANNUAL DELAY REDUCTION

YEAR 1

Arrival Delay

Reduction/Year

$= \frac{1}{120}$ [61] x [1] yr 1

= (   )

x (   )

L = (   )

[65] acft hr/yr

Departure Delay

Reduction/Year

$= \frac{1}{120}$ [63] x [1] yr 1

= (   )

(   )

T = (   )

= [67] acft hr/yr

TOTAL = [65] + [67]

= (   )

[69] acft hr/yr

YEAR 10

Arrival Delay

Reduction/Year

$= \frac{1}{120}$ [62] x [1] yr 10

= (   )

x (   )

L = (   )

[66] acft hr/yr

Departure Delay

Reduction/Year

$= \frac{1}{120}$ [64] x [1] yr 10

= (   )

(   )

T = (   )

= [68] acft hr/yr

= [66] + [68]

= (   )

[70] acft hr/yr

WORKSHEET # 5: AIRCRAFT AND PASSENGER BENEFITS

AVERAGE HOURLY OPERATING COST ON LANDING, K

			YEAR 1	YEAR 10
$2055 x	[20]	=	( )	( )
1427 x	[21]	=	( )	( )
1078 x	[22]	=	( )	( )
811 x	[23]	=	( )	( )
646 x	[24]	=	( )	( )
385 x	[25]	=	( )	( )
23 x	[26]	=	( )	( )
	K	=	$( )/HR [71]	$( )/HR [72]

AVERAGE HOURLY OPERATING COST ON TAKEOFF, C

			YEAR 1	YEAR 10
$1171 x	[20]	=	( )	( )
839 x	[21]	=	( )	( )
712 x	[22]	=	( )	( )
573 x	[23]	=	( )	( )
472 x	[24]	=	( )	( )
351 x	[25]	=	( )	( )
19 x	[26]	=	( )	( )
	C	=	$( )/HR [73]	$( )/HR [74]

ANNUAL OPERATING COST REDUCTION

		YEAR 1	YEAR 10
K•L	=	[71]x[65]) = ( )	[72]x[66] = ( )
+C•L	=	[73]x[67]) = +( )	[74]x[68] = +( )
S	=	$ ( ) [75]	$ ( ) [76]

	YEAR 1	YEAR 10
ANNUAL PASSENGER DELAY REDUCTION		
352 seats x [20]	= ( )	( )
236 seats x [21]	= ( )	( )
144 seats x [22]	= ( )	( )
122 seats x [23]	= ( )	( )
89 seats x [24]	= ( )	( )
46 seats x [25]	= ( )	( )
8 seats x [26]	=+( )	+( )
(Seats per acft)	= ( )	( )
x(load factor)	x( )	x( )
=(Pax per acft)	=( ) [77]	=( ) [78]
Annual Pax Hours Saved.	=[77]x[69]	=[78]x[70]
	=( ) [79] pax hrs	=( ) [80] pax hrs

WORKSHEET #6: VALUE OF AIRPORT DELAY REDUCTION

	YEAR 1	YEAR 10
AIRCRAFT OPERATING COST REDUCTION	[75]=$( )	[76]=$( )
ANNUAL PASSENGER HOURS SAVED x $12.50/HR	[79]= ( ) x $12.50	[80]= ( ) x $12.50
ANNUAL PASSENGER DOLLAR BENEFIT	= $( ) [81]	=$( ) [82]
TOTAL AIRPORT BENEFIT OF INVESTMENT	= [75]+[81] = $( ) [83]	= [76]+[82] =$( ) [84]

WORKSHEET #7: SYSTEM-WIDE BENEFITS

		YEAR 1	YEAR 10
AVERAGE DELAY PER OPERATION			
WITHOUT INVESTMENT	Arr Delay =	[53] = ( )	[54] = ( )
	Dep Delay =	[55] = ( )	[56] = ( )
	Total	= ( )	Total = ( )
	Avg Delay = ½(Total)	= ( ) [85] min/operation	Avg Delay = ½(Total) = ( ) [86] min/operation
WITH INVESTMENT	Arr Delay =	[57] = ( )	[58] = ( )
	Dep Delay =	[59] = ( )	[60] = ( )
	Total	= ( )	Total = ( )
	Avg Delay = ½(Total)	= ( ) [87] min/operation	Avg Delay = ½(Total) = ( ) [88] min/operation

	YEAR 1		YEAR 10	
B-DELAY PER OPERATION FROM FIGURE 25				
WITHOUT INVESTMENT +	Avg Delay = [85]		Avg Delay = [86]	
	Acft Type	B-Delay	Acft Type	B-Delay
	1, 2, 3	( )	1, 2, 3	( )
	4, 5	( )	4, 5	( )
	6	( )	6	( )
	7	( ) pax hrs	7	( ) pax hrs
WITH INVESTMENT −	Avg Delay = [87]		Avg Delay = [88]	
	Acft Type	B-Delay	Acft Type	B-Delay
	1, 2, 3	( )	1, 2, 3	( )
	4, 5	( )	4, 5	( )
	6	( )	6	( )
	7	( ) pax hrs	7	( ) pax hrs
B-DELAY REDUCTION =	Acft Type	B-Delay	Acft Type	B-Delay
	1, 2, 3	( ) [89]	1,2,3	( ) [89]
	4,5	( ) [90]	4, 5	( ) [90]
	6	( ) [91]	6	( ) [91]
	7	( ) [92] pax hrs	7	( ) [92] pax hrs

					YEAR 1	YEAR 10

AVERAGE B-DELAY REDUCTION PER OPERATION

Acft Type	Sched. Mix		B-Delay Reduct.		YEAR 1	YEAR 10
1	[6]	x	[89]	=	( )	( )
2	[7]	x	[89]	=	( )	( )
3	[8]	x	[89]	=	( )	( )
4	[9]	x	[90]	=	( )	( )
5	[10]	x	[90]	=	( )	( )
6	[11]	x	[91]	=	( )	( )
7	[12]	x	[92]	=	( )	( )
	AVG. B-DELAY REDUCTION			=	( ) [93] pax hr/op	( ) [94] pax hr/op

B-DELAY REDUCTION BENEFIT

				YEAR 1	YEAR 10
Scheduled Volume	x	Average B-Delay Reduction	=	[2]x[93]	[2]x[94]
			=	( )	( )
x(Value of Pax Time)				x($12.50)	x($12.50)
TOTAL SYSTEM-WIDE BENEFIT			=	\$( ) [95]	\$( ) [96]

WORKSHEET #8: REDUCED DIVERSIONS

FRACTION OF AIRCRAFT DIVERTED (FROM WIND DIAGRAM)

		WITHOUT INVESTMENT		WITH INVESTMENT		CHANGE DUE TO INVESTMENT		
SMALL	=	( )	-	( )	=	( )	=	[97]
LARGE	=	( )	-	( )	=	( )	=	[98]

NUMBER OF ITINERANT APPROACHES BY SIZE

		YEAR 1	YEAR 10
BY SMALL	= ½ [2]x[12]	=( )	=( )
	+ ½ [I]x[19]	+( )	+( )
	- ½ [2]x[19]	-( )	-( )
	= (Total)	=( ) [99]	=( ) [100]
BY LARGE	= ½[I] - [99]	=( ) [101]	=( ) [102]

NOTE: [I] indicates annual Itinerant operations as given in Reference (4) for YEAR 1 and YEAR 10.

	YEAR 1		YEAR 10	
NUMBER OF APPROACHES BY USER CLASS	AC	AT	AC	AT
½ (Annual Operations Ref. 1) =	( ) [103]	( ) [106]	( ) [109]	( ) [112]
% SMALL =	( )% [104]	( )% [107]	( )% [110]	( )% [113]
% LARGE =	( )% [105]	( )% [108]	( )% [111]	( )% [114]
% TOTAL =	100%	100%	100%	100%
SMALL	[103]x[104] = ( ) [115]	[106]x[107] ( ) [117]	[109]x[110] =( ) [119]	[112]x[113] ( ) [121]
LARGE	[103]x[105] = ( ) [116]	[106]x[108] ( ) [118]	[109]x[111] =( ) [120]	[112]x[114] ( ) [122]

	GA/MIL	GA/MIL
SMALL	[99]-[115]-[117] = ( ) [123]	[100]-[119]-[121] =( ) [124]
LARGE	[101]-[116]-[118] = ( ) [125]	[102]-[120]-[122] =( ) [126]

WORKSHEET #8

3/3

NUMBER OF DIVERSIONS AVERTED

	YEAR 1			YEAR 10		
	AC	AT	GM	AC	AT	GM
SMALL	[115] x[97] =( ) [127]	[117] x[97] =( ) [128]	[123] x[97] =( ) [129]	[119] x[97] =( ) [130]	[121] x[97] =( ) [131]	[124] x[97] =( ) [132]
LARGE	[116] x[98] =( ) [133]	[118] x[98] =( ) [134]	[125] x[98] =( ) [135]	[120] x[98] =( ) [136]	[122] x[98] =( ) [137]	[126] x[98] =( ) [138]
TOTAL	[127] +[133] ( ) [139]	[128] +[134] ( ) [140]	[129] +[135] ( ) [141]	[130] +[136] ( ) [142]	[131] +[137] ( ) [143]	[132] +[138] ( ) [144]

WORKSHEET #9: VALUE OF REDUCED DIVERSIONS

		YEAR 1	YEAR 10
AIR CARRIER			
PAX/FLT	=	n = ( )	n = ( )
COST/DIVERSION	=	$550+$148n=$( )*	$550+148n =$( )*
x DIVERSIONS AVERTED	=	[139] x( )	[142] x( )
AIR CARRIER BENEFIT	=	$( )	$( )
AIR TAXI			
PAX/FLT	=	n = ( )	n = ( )
$/DIVERSION	=	$30+$97n = ( )	$30+$97n = ( )
x DIVERSIONS AVERTED	=	[140] x( )	[143] x( )
AIR TAXI BENEFIT	=	$( )	$( )
GA AND MILITARY			
PAX/FLT	=	n = ( )	n = ( )
$/DIVERSION	=	$20+$46n = ( )	$20+$46n = ( )
x DIVERSIONS AVERTED	=	[141] x( )	[144] x( )
GA&MIL BENEFIT	=	$( )	$( )
TOTAL BENEFIT			
AC + AT + GM	=	$( )	$( )
		[145]	[146]

*For Non-Hub airports use $506+$148n
See text for representative values of n.

WORKSHEET #10: ESTIMATE TOTAL BENEFITS

	YEAR 1	YEAR 10
TOTAL AIRPORT BENEFITS from Worksheet #6, p 1/1	[83] =\$( )	[84] =\$( )
TOTAL SYSTEMWIDE BENEFITS from Worksheet #7, p 3/3	[95] = ( )	[96] = ( )
TOTAL DIVERSION BENEFITS from Worksheet #9, p 1/1	[145] = ( )	[146] = ( )
TOTAL INVESTMENT BENEFITS	B_1=\$( )	B_{10}=\$( )

TWENTY YEAR BENEFIT, DISCOUNTED TO YEAR 1*

$= 3.96x(B_1) + 5.40 \times (B_{10})$

= (   ).
[149]

* This formula is for a discount rate of 10%. If a discount rate other than 10% is to be employed, then the formula is:

$C_1 \times (B_1) + C_{10} \times (B_{10})$

where

C_1 = coefficient of B_1 from Table 11, page 111.

C_{10} = coefficient of B_{10} from **Table** 11, page 111.

WORKSHEET #11.1 COSTS FOR 1% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+ OPERATING EXPENSE	— OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(		)	x	1.0000	=	( )
( )	(		)	x	.9901	=	( )
( )	(		)	x	.9803	=	( )
( )	(		)	x	.9705	=	( )
( )	(		)	x	.9609	=	( )
( )	(		)	x	.9514	=	( )
( )	(		)	x	.9420	=	( )
( )	(		)	x	.9327	=	( )
( )	(		)	x	.9234	=	( )
( )	(		)	x	.9143	=	( )
( )	(		)	x	.9052	=	( )
( )	(		)	x	.8963	=	( )
( )	(		)	x	.8874	=	( )
( )	(		)	x	.8786	=	( )
( )	(		)	x	.8699	=	( )
( )	(		)	x	.8613	=	( )
( )	(		)	x	.8528	=	( )
( )	(		)	x	.8443	=	( )
( )	(		)	x	.8360	=	( )
( )	(		)	x	.8277	=	( )
( )	(		)	x	.8195	=	( )
( )	(		)	x	.8114	=	( )
( )	(		)	x	.8034	=	( )
( )	(		)	x	.7954	=	( )
		TOTAL COSTS DISCOUNTED TO BASE YEAR *				=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.2 COSTS FOR 2% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9803	=	( )
( )	( )	x	.9611	=	( )
( )	( )	x	.9423	=	( )
( )	( )	x	.9238	=	( )
( )	( )	x	.9057	=	( )
( )	( )	x	.8879	=	( )
( )	( )	x	.8705	=	( )
( )	( )	x	.8534	=	( )
( )	( )	x	.8367	=	( )
( )	( )	x	.8203	=	( )
( )	( )	x	.8042	=	( )
( )	( )	x	.7884	=	( )
( )	( )	x	.7730	=	( )
( )	( )	x	.7578	=	( )
( )	( )	x	.7430	=	( )
( )	( )	x	.7284	=	( )
( )	( )	x	.7141	=	( )
( )	( )	x	.7001	=	( )
( )	( )	x	.6864	=	( )
( )	( )	x	.6729	=	( )
( )	( )	x	.6597	=	( )
( )	( )	x	.6468	=	( )
( )	( )	x	.6341	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.3 COSTS FOR 3% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9708	=	( )
( )	( )	x	.9426	=	( )
( )	( )	x	.9151	=	( )
( )	( )	x	.8884	=	( )
( )	( )	x	.8626	=	( )
( )	( )	x	.8374	=	( )
( )	( )	x	.8130	=	( )
( )	( )	x	.7894	=	( )
( )	( )	x	.7664	=	( )
( )	( )	x	.7440	=	( )
( )	( )	x	.7224	=	( )
( )	( )	x	.7013	=	( )
( )	( )	x	.6809	=	( )
( )	( )	x	.6611	=	( )
( )	( )	x	.6418	=	( )
( )	( )	x	.6231	=	( )
( )	( )	x	.6050	=	( )
( )	( )	x	.5873	=	( )
( )	( )	x	.5702	=	( )
( )	( )	x	.5536	=	( )
( )	( )	x	.5375	=	( )
( )	( )	x	.5218	=	( )
( )	( )	x	.5066	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.4 COSTS FOR 4% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+	OPERATING EXPENSE	—	OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(				)	x	1.0000	=	( )
( )	(				)	x	.9615	=	( )
( )	(				)	x	.9245	=	( )
( )	(				)	x	.8890	=	( )
( )	(				)	x	.8548	=	( )
( )	(				)	x	.8219	=	( )
( )	(				)	x	.7903	=	( )
( )	(				)	x	.7599	=	( )
( )	(				)	x	.7306	=	( )
( )	(				)	x	.7025	=	( )
( )	(				)	x	.6755	=	( )
( )	(				)	x	.6495	=	( )
( )	(				)	x	.6246	=	( )
( )	(				)	x	.6005	=	( )
( )	(				)	x	.5774	=	( )
( )	(				)	x	.5552	=	( )
( )	(				)	x	.5339	=	( )
( )	(				)	x	.5133	=	( )
( )	(				)	x	.4936	=	( )
( )	(				)	x	.4746	=	( )
( )	(				)	x	.4563	=	( )
( )	(				)	x	.4388	=	( )
( )	(				)	x	.4219	=	( )
( )	(				)	x	.4057	=	( )
			TOTAL COSTS DISCOUNTED TO BASE YEAR *					=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.5 COSTS FOR 5% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9523	=	( )
( )	( )	x	.9070	=	( )
( )	( )	x	.8638	=	( )
( )	( )	x	.8227	=	( )
( )	( )	x	.7835	=	( )
( )	( )	x	.7462	=	( )
( )	( )	x	.7106	=	( )
( )	( )	x	.6768	=	( )
( )	( )	x	.6446	=	( )
( )	( )	x	.6139	=	( )
( )	( )	x	.5846	=	( )
( )	( )	x	.5568	=	( )
( )	( )	x	.5303	=	( )
( )	( )	x	.5050	=	( )
( )	( )	x	.4810	=	( )
( )	( )	x	.4581	=	( )
( )	( )	x	.4363	=	( )
( )	( )	x	.4155	=	( )
( )	( )	x	.3957	=	( )
( )	( )	x	.3768	=	( )
( )	( )	x	.3589	=	( )
( )	( )	x	.3418	=	( )
( )	( )	x	.3255	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.6 COSTS FOR 6% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.000	=	( )
( )	( )	x	.9434	=	( )
( )	( )	x	.8900	=	( )
( )	( )	x	.8396	=	( )
( )	( )	x	.7920	=	( )
( )	( )	x	.7472	=	( )
( )	( )	x	.7049	=	( )
( )	( )	x	.6650	=	( )
( )	( )	x	.6274	=	( )
( )	( )	x	.5919	=	( )
( )	( )	x	.5583	=	( )
( )	( )	x	.5267	=	( )
( )	( )	x	.4969	=	( )
( )	( )	x	.4688	=	( )
( )	( )	x	.4423	=	( )
( )	( )	x	.4172	=	( )
( )	( )	x	.3936	=	( )
( )	( )	x	.3713	=	( )
( )	( )	x	.3503	=	( )
( )	( )	x	.3305	=	( )
( )	( )	x	.3118	=	( )
( )	( )	x	.2941	=	( )
( )	( )	x	.2775	=	( )
( )	( )	x	.2618	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.7 COSTS FOR 7% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+ OPERATING EXPENSE	— OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(		)	x	1.0000	=	( )
( )	(		)	x	.9345	=	( )
( )	(		)	x	.8734	=	( )
( )	(		)	x	.8163	=	( )
( )	(		)	x	.7629	=	( )
( )	(		)	x	.7129	=	( )
( )	(		)	x	.6663	=	( )
( )	(		)	x	.6227	=	( )
( )	(		)	x	.5820	=	( )
( )	(		)	x	.5439	=	( )
( )	(		)	x	.5083	=	( )
( )	(		)	x	.4750	=	( )
( )	(		)	x	.4440	=	( )
( )	(		)	x	.4149	=	( )
( )	(		)	x	.3878	=	( )
( )	(		)	x	.3624	=	( )
( )	(		)	x	.3387	=	( )
( )	(		)	x	.3165	=	( )
( )	(		)	x	.2958	=	( )
( )	(		)	x	.2765	=	( )
( )	(		)	x	.2584	=	( )
( )	(		)	x	.2415	=	( )
( )	(		)	x	.2257	=	( )
( )	(		)	x	.2109	=	( )
		TOTAL COSTS DISCOUNTED TO BASE YEAR *				=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.8 COSTS FOR 8% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9259	=	( )
( )	( )	x	.8573	=	( )
( )	( )	x	.7938	=	( )
( )	( )	x	.7350	=	( )
( )	( )	x	.6805	=	( )
( )	( )	x	.6301	=	( )
( )	( )	x	.5834	=	( )
( )	( )	x	.5402	=	( )
( )	( )	x	.5002	=	( )
( )	( )	x	.4631	=	( )
( )	( )	x	.4288	=	( )
( )	( )	x	.3971	=	( )
( )	( )	x	.3677	=	( )
( )	( )	x	.3404	=	( )
( )	( )	x	.3152	=	( )
( )	( )	x	.2918	=	( )
( )	( )	x	.2702	=	( )
( )	( )	x	.2502	=	( )
( )	( )	x	.2317	=	( )
( )	( )	x	.2145	=	( )
( )	( )	x	.1986	=	( )
( )	( )	x	.1839	=	( )
( )	( )	x	.1703	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.9 COSTS FOR 9% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9174	=	( )
( )	( )	x	.8416	=	( )
( )	( )	x	.7721	=	( )
( )	( )	x	.7084	=	( )
( )	( )	x	.6499	=	( )
( )	( )	x	.5962	=	( )
( )	( )	x	.5470	=	( )
( )	( )	x	.5018	=	( )
( )	( )	x	.4604	=	( )
( )	( )	x	.4224	=	( )
( )	( )	x	.3875	=	( )
( )	( )	x	.3555	=	( )
( )	( )	x	.3261	=	( )
( )	( )	x	.2992	=	( )
( )	( )	x	.2745	=	( )
( )	( )	x	.2518	=	( )
( )	( )	x	.2310	=	( )
( )	( )	x	.2119	=	( )
( )	( )	x	.1944	=	( )
( )	( )	x	.1784	=	( )
( )	( )	x	.1637	=	( )
( )	( )	x	.1501	=	( )
( )	( )	x	.1377	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.10 COSTS FOR 10% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	x	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9090	=	( )
( )	( )	x	.8264	=	( )
( )	( )	x	.7513	=	( )
( )	( )	x	.6830	=	( )
( )	( )	x	.6209	=	( )
( )	( )	x	.5644	=	( )
( )	( )	x	.5131	=	( )
( )	( )	x	.4665	=	( )
( )	( )	x	.4241	=	( )
( )	( )	x	.3855	=	( )
( )	( )	x	.3504	=	( )
( )	( )	x	.3186	=	( )
( )	( )	x	.2896	=	( )
( )	( )	x	.2633	=	( )
( )	( )	x	.2393	=	( )
( )	( )	x	.2176	=	( )
( )	( )	x	.1978	=	( )
( )	( )	x	.1798	=	( )
( )	( )	x	.1635	=	( )
( )	( )	x	.1486	=	( )
( )	( )	x	.1351	=	( )
( )	( )	x	.1228	=	( )
( )	( )	x	.1116	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.11 COSTS FOR 11% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.9009	=	( )
( )	( )	x	.8116	=	( )
( )	( )	x	.7311	=	( )
( )	( )	x	.6587	=	( )
( )	( )	x	.5934	=	( )
( )	( )	x	.5346	=	( )
( )	( )	x	.4816	=	( )
( )	( )	x	.4339	=	( )
( )	( )	x	.3909	=	( )
( )	( )	x	.3521	=	( )
( )	( )	x	.3172	=	( )
( )	( )	x	.2858	=	( )
( )	( )	x	.2575	=	( )
( )	( )	x	.2319	=	( )
( )	( )	x	.2090	=	( )
( )	( )	x	.1882	=	( )
( )	( )	x	.1696	=	( )
( )	( )	x	.1528	=	( )
( )	( )	x	.1376	=	( )
( )	( )	x	.1240	=	( )
( )	( )	x	.1117	=	( )
( )	( )	x	.1006	=	( )
( )	( )	x	.0906	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET # 11.12 COSTS FOR 12% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.8928	=	( )
( )	( )	x	.7971	=	( )
( )	( )	x	.7117	=	( )
( )	( )	x	.6355	=	( )
( )	( )	x	.5674	=	( )
( )	( )	x	.5066	=	( )
( )	( )	x	.4523	=	( )
( )	( )	x	.4038	=	( )
( )	( )	x	.3606	=	( )
( )	( )	x	.3219	=	( )
( )	( )	x	.2874	=	( )
( )	( )	x	.2566	=	( )
( )	( )	x	.2291	=	( )
( )	( )	x	.2046	=	( )
( )	( )	x	.1827	=	( )
( )	( )	x	.1631	=	( )
( )	( )	x	.1456	=	( )
( )	( )	x	.1300	=	( )
( )	( )	x	.1161	=	( )
( )	( )	x	.1036	=	( )
( )	( )	x	.0925	=	( )
( )	( )	x	.0826	=	( )
( )	( )	x	.0737	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.13 COSTS FOR 13% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.8849	=	( )
( )	( )	x	.7831	=	( )
( )	( )	x	.6930	=	( )
( )	( )	x	.6133	=	( )
( )	( )	x	.5427	=	( )
( )	( )	x	.4803	=	( )
( )	( )	x	.4250	=	( )
( )	( )	x	.3761	=	( )
( )	( )	x	.3328	=	( )
( )	( )	x	.2945	=	( )
( )	( )	x	.2607	=	( )
( )	( )	x	.2307	=	( )
( )	( )	x	.2041	=	( )
( )	( )	x	.1806	=	( )
( )	( )	x	.1598	=	( )
( )	( )	x	.1415	=	( )
( )	( )	x	.1252	=	( )
( )	( )	x	.1108	=	( )
( )	( )	x	.0980	=	( )
( )	( )	x	.0867	=	( )
( )	( )	x	.0768	=	( )
( )	( )	x	.0679	=	( )
( )	( )	x	.0601	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.14 COSTS FOR 14% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+ OPERATING EXPENSE	— OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(		)	x	1.0000	=	( )
( )	(		)	x	.8771	=	( )
( )	(		)	x	.7694	=	( )
( )	(		)	x	.6749	=	( )
( )	(		)	x	.5920	=	( )
( )	(		)	x	.5193	=	( )
( )	(		)	x	.4555	=	( )
( )	(		)	x	.3996	=	( )
( )	(		)	x	.3505	=	( )
( )	(		)	x	.3075	=	( )
( )	(		)	x	.2697	=	( )
( )	(		)	x	.2366	=	( )
( )	(		)	x	.2075	=	( )
( )	(		)	x	.1820	=	( )
( )	(		)	x	.1597	=	( )
( )	(		)	x	.1401	=	( )
( )	(		)	x	.1228	=	( )
( )	(		)	x	.1078	=	( )
( )	(		)	x	.0945	=	( )
( )	(		)	x	.0829	=	( )
( )	(		)	x	.0727	=	( )
( )	(		)	x	.0638	=	( )
( )	(		)	x	.0559	=	( )
( )	(		)	x	.0491	=	( )
		TOTAL COSTS DISCOUNTED TO BASE YEAR *				=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.15 COSTS FOR 15% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+	OPERATING EXPENSE	—	OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(				)	x	1.0000	=	( )
( )	(				)	x	.8695	=	( )
( )	(				)	x	.7561	=	( )
( )	(				)	x	.6575	=	( )
( )	(				)	x	.5717	=	( )
( )	(				)	x	.4971	=	( )
( )	(				)	x	.4323	=	( )
( )	(				)	x	.3759	=	( )
( )	(				)	x	.3269	=	( )
( )	(				)	x	.2842	=	( )
( )	(				)	x	.2471	=	( )
( )	(				)	x	.2149	=	( )
( )	(				)	x	.1869	=	( )
( )	(				)	x	.1625	=	( )
( )	(				)	x	.1413	=	( )
( )	(				)	x	.1228	=	( )
( )	(				)	x	.1068	=	( )
( )	(				)	x	.0929	=	( )
( )	(				)	x	.0808	=	( )
( )	(				)	x	.0702	=	( )
( )	(				)	x	.0611	=	( )
( )	(				)	x	.0531	=	( )
( )	(				)	x	.0462	=	( )
( )	(				)	x	.0401	=	( )
			TOTAL COSTS DISCOUNTED TO BASE YEAR *					=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.16 COSTS FOR 16% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+ OPERATING EXPENSE	— OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(		)	x	1.0000	=	( )
( )	(		)	x	.8620	=	( )
( )	(		)	x	.7431	=	( )
( )	(		)	x	.6406	=	( )
( )	(		)	x	.5522	=	( )
( )	(		)	x	.4761	=	( )
( )	(		)	x	.4104	=	( )
( )	(		)	x	.3538	=	( )
( )	(		)	x	.3050	=	( )
( )	(		)	x	.2629	=	( )
( )	(		)	x	.2266	=	( )
( )	(		)	x	.1954	=	( )
( )	(		)	x	.1684	=	( )
( )	(		)	x	.1452	=	( )
( )	(		)	x	.1252	=	( )
( )	(		)	x	.1079	=	( )
( )	(		)	x	.0930	=	( )
( )	(		)	x	.0802	=	( )
( )	(		)	x	.0691	=	( )
( )	(		)	x	.0596	=	( )
( )	(		)	x	.0513	=	( )
( )	(		)	x	.0443	=	( )
( )	(		)	x	.0381	=	( )
( )	(		)	x	.0329	=	( )
		TOTAL COSTS DISCOUNTED TO BASE YEAR *				=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.17 COSTS FOR 17% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE − OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.8547	=	( )
( )	( )	x	.7305	=	( )
( )	( )	x	.6243	=	( )
( )	( )	x	.5336	=	( )
( )	( )	x	.4561	=	( )
( )	( )	x	.3898	=	( )
( )	( )	x	.3332	=	( )
( )	( )	x	.2847	=	( )
( )	( )	x	.2434	=	( )
( )	( )	x	.2080	=	( )
( )	( )	x	.1778	=	( )
( )	( )	x	.1519	=	( )
( )	( )	x	.1298	=	( )
( )	( )	x	.1110	=	( )
( )	( )	x	.0948	=	( )
( )	( )	x	.0811	=	( )
( )	( )	x	.0693	=	( )
( )	( )	x	.0592	=	( )
( )	( )	x	.0506	=	( )
( )	( )	x	.0432	=	( )
( )	( )	x	.0369	=	( )
( )	( )	x	.0316	=	( )
( )	( )	x	.0270	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.18 COSTS FOR 18% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.8474	=	( )
( )	( )	x	.7181	=	( )
( )	( )	x	.6086	=	( )
( )	( )	x	.5157	=	( )
( )	( )	x	.4371	=	( )
( )	( )	x	.3704	=	( )
( )	( )	x	.3139	=	( )
( )	( )	x	.2660	=	( )
( )	( )	x	.2254	=	( )
( )	( )	x	.1910	=	( )
( )	( )	x	.1619	=	( )
( )	( )	x	.1372	=	( )
( )	( )	x	.1162	=	( )
( )	( )	x	.0985	=	( )
( )	( )	x	.0835	=	( )
( )	( )	x	.0707	=	( )
( )	( )	x	.0599	=	( )
( )	( )	x	.0508	=	( )
( )	( )	x	.0430	=	( )
( )	( )	x	.0365	=	( )
( )	( )	x	.0309	=	( )
( )	( )	x	.0262	=	( )
( )	( )	x	.0222	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.19 COSTS FOR 19% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT + OPERATING EXPENSE — OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	( )	x	1.0000	=	( )
( )	( )	x	.8403	=	( )
( )	( )	x	.7061	=	( )
( )	( )	x	.5934	=	( )
( )	( )	x	.4986	=	( )
( )	( )	x	.4190	=	( )
( )	( )	x	.3521	=	( )
( )	( )	x	.2959	=	( )
( )	( )	x	.2486	=	( )
( )	( )	x	.2089	=	( )
( )	( )	x	.1756	=	( )
( )	( )	x	.1475	=	( )
( )	( )	x	.1240	=	( )
( )	( )	x	.1042	=	( )
( )	( )	x	.0875	=	( )
( )	( )	x	.0735	=	( )
( )	( )	x	.0618	=	( )
( )	( )	x	.0519	=	( )
( )	( )	x	.0436	=	( )
( )	( )	x	.0367	=	( )
( )	( )	x	.0308	=	( )
( )	( )	x	.0259	=	( )
( )	( )	x	.0217	=	( )
( )	( )	x	.0183	=	( )
	TOTAL COSTS DISCOUNTED TO BASE YEAR *			=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #11.20 COSTS FOR 20% DISCOUNT FACTOR

YEAR	(CAPITAL INVESTMENT	+	OPERATING EXPENSE	—	OPERATING RECEIPTS)	X	DISCOUNT FACTOR	=	($K)
(19)*	(				)	x	1.0000	=	( )
( )	(				)	x	.8333	=	( )
( )	(				)	x	.6944	=	( )
( )	(				)	x	.5787	=	( )
( )	(				)	x	.4822	=	( )
( )	(				)	x	.4018	=	( )
( )	(				)	x	.3349	=	( )
( )	(				)	x	.2790	=	( )
( )	(				)	x	.2325	=	( )
( )	(				)	x	.1938	=	( )
( )	(				)	x	.1615	=	( )
( )	(				)	x	.1345	=	( )
( )	(				)	x	.1121	=	( )
( )	(				)	x	.0934	=	( )
( )	(				)	x	.0778	=	( )
( )	(				)	x	.0649	=	( )
( )	(				)	x	.0540	=	( )
( )	(				)	x	.0450	=	( )
( )	(				)	x	.0375	=	( )
( )	(				)	x	.0313	=	( )
( )	(				)	x	.0260	=	( )
( )	(				)	x	.0217	=	( )
( )	(				)	x	.0181	=	( )
( )	(				)	x	.0150	=	( )
			TOTAL COSTS DISCOUNTED TO BASE YEAR *					=	( ) [150]

*The first year listed is taken to be the BASE YEAR

WORKSHEET #12: COMPARE BENEFITS AND COSTS

DISCOUNT BENEFITS TO BASE YEAR OF COSTS

$t_1 - t_B$ = (YEAR 1 OF BENEFITS) - (BASE YEAR OF COSTS)
= ( ) - ( )
= ( )
[151]

TWENTY YEAR BENEFIT, DISCOUNTED TO BASE YEAR*
= [149] / $(1.10)^{t_1 - t_B}$
= ( )
[152]

BENEFIT/COST COMPARISON
[TOTAL BENEFITS, DISCOUNTED TO BASE YEAR
÷ TOTAL COSTS, DISCOUNTED TO BASE YEAR]
= [152]/[150]
= ( )

* This formula is for a discount rate of 10% . If a discount rate other than 10% is to be employed, then the formula is:

[149]/$(1. + R/100)^{t_1 - t_B}$

Where R is the percent discount rate.

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